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## Metasomatic Processes in Fissure-Veins.\*

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## PART I.

### GENERAL FEATURES.

#### *Purpose and Extent of Inquiry.*

A study of the changes in rocks contiguous to ore-bearing fissures is essential to a thorough understanding of the genesis of such deposits. Nevertheless, comparatively little work has been done in this direction, though many mining geologists (for instance, Groddeck) long ago emphatically declared the necessity of such investigations. Ores and structure have been dealt with in detail; but the important changes which adjacent rocks of known composition have suffered are too often briefly dismissed, or even incorrectly indicated. It is the purpose of this review to collect the scattered data relating to the alteration of rocks near or between fissures; to indicate the principal active processes; to classify the veins, if possible, according to the different phases of alteration accompanying them; and, finally, to draw some conclusions from the facts thus grouped. This first attempt to systematize the metasomatic data of fissure-veins is by no means complete: only such parts of the American and foreign literature are represented as were deemed to be of vital importance. The discussion principally involves the changes which the country-rock has undergone, whether they have resulted in the formation of *ores* or not; and, in the second place, some space is devoted to such alterations as fissure-veins already formed sometimes suffer through certain secondary agencies. I have excluded, however, all references to weathering, or to the decomposition of vein-materials near the surface by waters containing free oxygen. It is often difficult to draw the line between normal fissure-veins and deposits not



to be regarded as such, strictly speaking, but clearly due to the same genetic causes; and some of the latter class have been included in this discussion.

*Definitions.*

*Fissure-Veins.*—For the present discussion, a fissure-vein may be regarded as a mineral mass, tabular in form, as a whole, though frequently irregular in detail, occupying or accompanying a fracture or set of fractures in the enclosing rock; this mineral mass has been formed later than the country-rock and the fracture, either through the filling of open spaces along the latter, or through chemical alteration of the adjoining rock. Such alteration does not ordinarily extend far from the fissure. Only in regions where the vein-forming agencies have acted with unusual intensity, a partial alteration may extend over larger areas. These zones of alteration being genetically connected with the veins proper, must necessarily also be considered in this discussion.

*Metamorphism.*—This term, meaning strictly a change of form, was proposed by Lyell in 1831, and has since been employed in a wider sense, so as to cover any change in the composition or structure of a rock, through whatever agency, and whether with or without gain or loss of substance.

*Metasomatism.*—This name, meaning a "change of body," is given to that variety of metamorphism which involves a change in the chemical composition of rocks, by the addition or subtraction of substance.\* The terms "replacement," "substitution," "alteration," etc., have been employed in discussions of metasomatism with different shades of meaning. A review of the classification of pseudomorphs, which form the origin of our knowledge of metasomatism, will throw light upon the nomenclature of the subject.

The occurrence of organic remains, consisting of material of which they were certainly not originally composed, called attention to the remarkable transformation now known as metasomatic replacements. As instances, we may recall corals changed into quartz, belemnites converted into barite, and shells of bivalves or gasteropods transformed into pyrite, chalcocite,

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\* Dana (*Man. of Geol.*, 4th ed., p. 314) proposes for the same process the term "metachemic;" but this has not found general acceptance.



sphalerite or specularite. To the same order of phenomena belongs the silicified wood, in which the organic substance has been removed and replaced with silica so delicately as to preserve in minute detail the original organic structure. This replacement is probably due to the precipitation of silica from solution by the acids generated in the decay of organic matter. More rarely, wood and plant-remains may be replaced by pyrite, chalcocite, galenite, cinnabar, barite, limonite, malachite, etc.

But it is the study of pseudomorphs, showing one mineral appearing in the crystal-form of another, that has led to a more detailed knowledge of the chemical laws which govern these remarkable changes. Here was conclusive proof that one mineral, definitely crystallized, had changed into another, sometimes totally different, substance. Naumann says of pseudomorphs :

“Their importance cannot be overestimated, because they enable us to study successfully the laws of the processes which are constantly acting in the rocks and constantly changing them ; for the pseudomorphs represent only one special case of the grand process of chemical alteration going on in the mineral kingdom : namely, that in which the form remained in spite of the change. From these we may draw conclusions as to the chemical processes going on in rocks which may change each grain to another mineral.”\*

Blum, who made the first extensive examination of pseudomorphs, divided them into: (1) those produced by partial change in the composition of the original mineral (one or more elements being removed, added or introduced by substitution); and (2) those produced by a complete replacement of the original mineral with another. (This class includes both those produced by chemical replacement and by previous solution and subsequent filling.)

Naumann, in his well-known text-book of Mineralogy, divided the pseudomorphs into: (1) hypostatic pseudomorphs, formed by the mechanical deposition of substance outwards or inwards from the limiting planes, and again subdivided into pseudomorphs by covering, and pseudomorphs by filling; (2) metasomatic pseudomorphs, formed by the alteration of the substance by means of its molecular replacement with another mineral while the form has been preserved. The metasomatic

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\* *Mineralogie*, Naumann-Zirkel, 10th ed., Leipzig, p. 112.



pseudomorphs are also designated as "alteration" (*Umwandlung*) pseudomorphs. This, it will be noted, is the first introduction of the word *metasomatic* in technical literature. In nearly all cases, the metasomatic pseudomorphs involve chemical action.

Naumann further divides the metasomatic pseudomorphs into three classes, in which, respectively, (a) the original and the secondary substance are identical in chemical constituents ("paramorphic" pseudomorphs); or (b) chemical alteration has left one or more elements of the original in the secondary substance; or (c) the replacement of constituents has been complete, as in the substitution of galenite for calcite, or pyrite for quartz, but the process has been, nevertheless, a chemical one, since the removal and deposition have proceeded simultaneously, molecule for molecule. The second of these classes is again subdivided, according as the change involved simply the loss of original components (as in the formation of argentine from pyrargyrite), or the addition of components (*e.g.*, anglesite from galenite), or the exchange of components (*e.g.*, sericite from oligoclase).

The conceptions of Blum were introduced into English technical literature by James D. Dana,\* who divided pseudomorphs into those formed: (1) by infiltration (mechanical deposition in a mould already formed); (2) by incrustation (mechanical covering of crystals); (3) by replacement, one mineral gradually replacing another, and assuming at the same time its form, without any interchange of elements (the process being in a certain sense chemical, and wholly different from simple deposition); (4) by alteration, some of the elements being removed or exchanged, or new ones being added; and (5) by allomorphism, without chemical alteration; the body changing to one of the same composition but of different crystallographic system (the paramorphic pseudomorphs of Naumann).

Somewhat extreme views, differing from the above, were advanced by T. Sterry Hunt,† who classed pseudomorphs as: (1) those produced by chemical alteration, meaning by this a partial exchange of constituents (*e.g.*, limonite after siderite); and (2) those produced by substitution or replacement (these

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\* *American Journal of Science*, vol. 48, 1845, p. 81.

† *Systematic Mineralogy*, New York, 1892, p. 111.



terms being evidently regarded as equivalent). The latter he believed to be produced by deposition in spaces left by the removal of some other matter. The form of the original substance is assumed by the material which displaces, or is substituted for it, *e.g.*, quartz after calcite, barite, etc. While thus admitting partial alterations, Hunt makes a special case of a complete replacement, refusing to consider it as a chemical process, and regarding it always as an instance of separate dissolving and refilling. To the theory of metasomatism, which maintains that all the chemical elements in a crystal may be removed, and by molecular processes replaced with foreign substances, Sterry Hunt was strongly opposed.

Pseudomorphs of the second group proposed by him are, as is well known, of frequent occurrence, and correspond to Naumann's hypostatic division or pseudomorphs formed by mechanical deposition. Spaces of dissolution, subsequently filled, are also common enough in rocks, and may usually be readily identified as such under the microscope. But that molecular replacement, as defined by Naumann and Dana, also exists, and, moreover, is of the highest importance, seems at present beyond doubt.

As the essential process of metasomatism applies as well to an irregular grain as to a perfectly developed crystal, we are justified in extending the conception to aggregates of grains of one or several minerals; in other words, to rocks and mineral aggregates in general. In this sense C. R. Van Hise\* has defined metasomatism as "the process of metamorphism by which original minerals are partly or wholly altered into other minerals, or are replaced by other minerals, or are recrystallized without chemical changes, or one or all of these together." S. F. Emmons has defined metasomatism as follows:†

"By metasomatic exchange is meant an interchange of substance without necessarily involving, as does pseudomorphism, the preservation of the original form of the substance replaced, or even of its original volume."

A second definition, based on the consideration that practically simultaneous solution and deposition could certainly be proved

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\* "Principles of Pre-Cambrian Geology," 16th Ann. Rept., U. S. Geol. Sur., part i., p. 689.

† U. S. Geol. Surv., Monogr. XII., p. 565.



for many cases, where the exact proof of chemical-molecular replacement could not be furnished, is given by Mr. Emmons as follows:\*

“By metasomatic interchange I understand an interchange of substance, but not necessarily molecule by molecule, in such a manner as to preserve the original structure, form or volume of the substance replaced.”

The fundamental difficulty is that the final result does not always indicate the particular pseudomorphic process which has preceded. Mechanical deposition, for instance, may follow so closely after dissolution, that the two processes really appear as one. It may also be said that molecular replacement is difficult to prove, as molecular processes cannot be followed with the microscope; and this is, in a sense, true. We may assert, however, that, with the highest magnifying powers, we are able to follow the transformation of quartz, for instance, into sericite, or into calcite, or into siderite, without finding the slightest indication of an intermediate stage of open space. The fiber and blades of sericite project into the quartz without the slightest break in the contact; the rhombohedrons of siderite develop in quartzite, their crystal faces cutting across the grains without any interstices. Perfect tourmaline prisms develop in feldspar grains, and sharp cubes of pyrite in primary granitic quartz.

In cases of complete molecular replacement, such as galena after calcite, the replacing mineral was probably present in the solution, partly dissociated or ionized. The solution of a certain quantity of the original mineral caused the separation of a corresponding quantity of the ions of the replacing substance, according to physico-chemical laws. If carried out on these lines, the process is necessarily molecular and chemical. Where there were two solutions—one dissolving, the other depositing—and where a certain time intervened, the process is a mechanical one and should not, I think, be considered metasomatic. In many cases the distinction may be very difficult to draw.

In conclusion, metasomatism might be defined as the process by which a mineral has suffered, through chemical processes, a partial or complete change in its chemical constitution. Rocks or aggregates of minerals are “metasomatic,” if any or

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\* “The Genesis of Certain Ore-Deposits,” *Trans.*, xv., 124, 1886.



all of the constituent minerals have undergone such changes. This definition excludes the process of paramorphism which, as already emphasized by Naumann, is exceedingly rare.

In the use of the term *alteration* it would perhaps be best to follow Dana and let it mean a partial change of substance in a mineral or rock. *Decomposition*, it would seem advisable to restrict to the cases in which a mineral or rock is dissolved into its component parts; and a principal use for it would be found in the processes of weathering.

As has been shown, the words *replacement* and *substitution* have been used in very different ways. The majority of recent authors use them both as equivalent to metasomatism. Dana, however, applies *replacement* to a complete exchange of substance, reserving *alteration* for a partial loss, gain or interchange of elements; while Sterry Hunt gives the name of *replacement* or *substitution* to mechanical dissolution and the filling of the resultant cavities.

The chemist has, however, a distinct definition of *substitution* as "the replacing of one or more elements or radicals in a compound by other elements or compounds;" and it would probably be best to adhere to this, and discard *substitution* as a synonym for metasomatism or alteration.

*Replacement* is, in its general meaning, nearly identical with *substitution*, although it has no such distinct chemical use. It would seem advisable to regard it as a synonym of metasomatism, distinguishing, for the sake of convenience, between partial and complete replacement. This is contrary to Dana's distinction; but the word has been used so generally during late years in this wider sense that it seems best to retain this meaning for it.

*Impregnation*.—This term has been applied in so many different ways—to primary disseminations; to minerals formed by replacement; and to the filling of cavities or interstitial spaces in rocks—that it might well be rejected altogether as a genetic term, and used only in a structural sense, as descriptive of finely divided material disseminated in a differing mineral or rock-mass.

*Cementation*.—This term, proposed by Prof. C. R. Van Hise,\*

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\* "Pre-Cambrian Geology." 17th Ann. Report U. S. G. S., part i., p. 686.



is convenient and expressive for the purpose of indicating filling of interstices in porous or shattered rocks. Cementation assumes importance in proportion to the porosity of the rock, which, in sandstones and tuffs, may reach 10 or 20 per cent. In most intrusive igneous rocks the porosity is so small as to be a negligible quantity.

*Weathering.*—Under this name are included the changes of rocks near the surface in cohesion and composition, due to the decomposing and oxidizing action of percolating waters above the permanent water-level. The tendency of weathering is to destroy the rock as a geological unit. The final results of metasomatic action are a few resistant minerals, such as quartz, kaolin and limonite. The formation of serpentine, chlorite, epidote and (ordinarily) pyrite is not weathering, but is due to more deeply seated causes. The German usage of *Verwittering*, to cover all secondary changes, due to weathering, thermal and other causes, seems highly objectionable, and especially apt to lead to many misconceptions.

In view of the difference of usage as to many of the above definitions, it is to be hoped that writers upon this subject will take pains to indicate the sense in which the various terms are employed by them.

*Metasomatism in Connection with Mineral Deposits, Especially  
Fissure-Veins.*

It was not long before the principles of metasomatic action, learned by the study of pseudomorphs, were applied to larger masses of rocks. This led, perhaps inevitably, to exaggerated notions, such as that of the formation of true granites from sediments and limestone,\* etc.; and this undue extension was followed by a reaction, exemplified in Sterry Hunt's writings.

The observation that ores may be found, not only in the clearly defined vein-filling, but also in the rock adjacent to the fissure, is contemporaneous with almost the earliest scientific records of mining. Sandberger† mentions the occurrence of masses of native silver, found in 1786 in the altered granite of certain Schwartzwald veins, which greatly astonished the old miners. Vogelgesang,‡ in Cotta's "Gangstudien," describes

\* G. Bischof, *Chem. Geol.*, Bonn, 1866, vol. iii., p. 34.

† *Erzgänge*, part ii., p. .

‡ Vol. ii., Freiberg, 1864, p. 78.



the dissemination of argentite, native silver, and various sulphides, in the gneiss adjoining certain veins near Freiberg.

But whether or not it contains ore, the rock adjoining a vein is very commonly softened, bleached and altered for some distance away from the fissure. This phenomenon has been explained in two radically different ways :

1. Bischof says :\*

“As we find ores in veins, proportionate in quantity to the alteration of the country-rock, what other relation can be thought to exist between the two facts than that the abundance of the ore is a result of this alteration?”

Sandberger says :†

“The extent of the alteration on both sides of the vein corresponds with the area from which the products of leaching have been carried to the vein.”

2. The opponents of these views say that the narrow zone of alteration, intense next to the fissure and gradually fading away within a short distance from it, most clearly indicates an agency within the fissure, acting with gradually diminishing energy on the adjoining strip of rock. They also point out that Bischof's premise, *i.e.*, the coincidence of richness of vein and extent of the altered zone, is not true as a universal proposition. And they show, further, that as the whole altered zone has, in many cases, received an addition of the same metals as are contained in the vein which may more than counterbalance its losses of other constituents, Sandberger's conclusion can certainly not have a general application; and finally, that, in those veins which have no gangue, but in which the ore has accumulated in the rock during the alteration, the incorrectness of that conclusion is particularly apparent.

Veins carrying cassiterite early attracted attention, as being almost always accompanied by ore impregnating the surrounding country-rock. The metasomatic character of the process was first shown by Daubrée‡ and later by Cotta,§ both of whom, in support of their views, call attention to the well-known occurrence of cassiterite as a pseudomorph after feldspar. Both explain the alteration as due to gradual replace-

\* *Chem. Geologie*, Bonn, 1866, vol. iii., p. 666.

† *Erzgänge*, vol. i., p. 149.

‡ *Ann. d. Mines*, 1841, xix., pp. 61, 72, 83.

§ *Die Lehre von den Lagerstätten*, Freiberg, 1859.



ment by the agency of thermal waters. This explanation was substantiated by more recent and detailed investigations; for instance, by Richard Pearce (1864) and LeNeve Foster (1877) in regard to Cornwall; and by A. W. Stelzner (1864) for Geyer, Saxony.

The views of Cotta concerning the alteration of the wall-rocks or veins are well expressed in the following paragraph:\*

“When lodes are accompanied by impregnations, it is to be assumed that generally the solutions from which the material of the lode were precipitated—they may have been aqueous, igneous, fluid or gaseous—also penetrated the wall-rock and there caused certain deposits in fine clays or in the rock itself. In the last case, crystals have made room for themselves by their power of crystallization; or an ore took the place of the mineral dissolved; for example, cassiterite, that of feldspar.”

This quotation shows plainly the clear conception which Cotta had of the alteration of rocks, as due, not only to filling of pores and cracks, but also to processes of replacement active within the rocks.

Although Cotta made no special division of replacement-veins, he was well aware of their occurrence and perfectly able to distinguish them from filled spaces. Describing the gold-veins of Tauern (Austria),† he says that they have not the character of clearly opened and filled fractures, but consist of several parallel tight fissures, between which lies more or less impregnated and altered country-rock. The gold penetrates into the country-rock from the fissure, and the tenor decreases gradually with increasing distance.

In 1873 Posepny published his famous examinations of the Raibl deposits.‡ These are not connected with fissures, but deserve mention, since entirely similar processes are active in fissure-veins. Posepny found that carbonate of zinc had replaced carbonate of lime “by metamorphic processes.”

Von Groddeck, in his well known text-book (1877), includes “metamorphic” deposits in his system, but limits them to replacements of limestone by zinc-, iron- and manganese-minerals. At about the same time, Stelzner, in his lectures, introduced a corresponding division of “metasomatic deposits,”

\* *A Treatise on Ore-Deposits.* (Prime's Translation.) New York, 1870, p. 90.

† *Die Lehre von den Erzlagertstätten*, Freiberg, 1859, p. 318.

‡ *Jahrbuch d. k. k. Geol. Reichsanstadt*, xxiii., 1873, p. 317.



though they were still limited to a relatively small number of the irregular masses in limestone.

Raphael Pumpelly was, I believe, the first who applied the principles of metasomatism to ore-deposits in this country, in describing the copper-deposits of Michigan (in part fissure-veins) in vol. i. of the Geological Survey of Michigan (1873), and in his noted paper on the "Metasomatic Development of the Copper-Bearing Rocks of Lake Superior."\* The copper, to a great extent, replaces other minerals.

In 1879 J. A. Church published a volume on the Comstock mines,† in which he maintained the origin of the quartz by replacement acting from a number of narrow fissures.

In 1882, S. F. Emmons first published the results of his examinations of the Leadville silver-lead deposits, in which it was shown that these were entirely formed by metasomatic replacement of the limestone by galena and other minerals. A little later, J. S. Curtis published his first results in regard to the silver-lead deposits of Eureka, Nevada, in which he arrived at substantially the same results as Mr. Emmons. Though these deposits, as well as those of Leadville, are not to be regarded as fissure-veins, it was evident that the same process might be considered as active along fissures, provided the waters circulating in them had the composition attributed to those of Leadville and Eureka. The results obtained were certainly of the greatest interest to students of fissure-veins, and threw a new light on many obscure facts. During the following years, Mr. Emmons, who had visited a great number of mining regions in the West containing fissure-veins, published several papers,‡ in which he maintained that, for a great number of the veins formerly considered as containing ore deposited in open spaces, another and much more plausible explanation could be advanced, namely, that, in many cases, the fissures had not been opened to any noteworthy extent, but only so much as to admit the passage of the mineral-bearing waters. The latter had attacked the rock on either side of the fissure, and, by a process of metasomatic replacement, had deposited ores in the place of

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\* *Proc. Am. Acad. Arts and Sci.*, vol. xiii., 1878.

† *The Comstock Lode*. New York, 1879.

‡ "The Genesis of Certain Ore-Deposits," *Trans.*, xv., 124, 1886; "The Structural Relations of Ore-Deposits," *Trans.*, xvi., 804, 1887.



the simultaneously dissolved rock-constituents. Applying this process to composite veins, consisting of a number of narrow fissures, and considering that gradual replacement had taken place, extending into the rock on each side of each smaller fissure, Mr. Emmons succeeded in showing how, under certain circumstances, a banded structure such as had ordinarily been attributed to the filling of open spaces could to some extent result from the process of replacement.

During the following years the theory of the formation of fissure-veins by replacement rapidly gained ground; and for some time it seemed as if the old view of deposition in open spaces were doomed to complete extinction. Carried away with the importance and interest of the metasomatic theory, many geologists and mining engineers extended its teachings beyond proper bounds, and were prone to speak of any fissure-vein as unquestionably a product of replacement. Attempts were made to show that open fissures could not exist unsupported, at any rate below the most superficial depths; and facts and proofs were too often neglected for bare assertions that metasomatic replacement had taken place. Posepny, in the discussion of his paper,\* protested against this unwarranted extension of a most excellent and well founded theory, and stated with some force that the experience and observations of a hundred years were not to be thrown away without very careful scrutiny. The pendulum had now swung to its extreme position; and it was not unnatural that a reaction should follow. It gradually became clear on the one hand that open spaces can and do exist down to a depth of many thousand feet,† and that these open cavities may be filled by the action of mineral-bearing water. On the other hand, it is evident that there is ample room for processes of replacement in fissure-veins, which may either affect the surrounding country-rock without producing notable amounts of ore, or, on the other hand, may attack it in such a way as to convert it wholly or partially into valuable minerals.

Some kind of metasomatic action is usually noticeable in the rock adjoining the fissure. But it is not to be denied that in many cases this alteration is very slight; and in a few veins it may be entirely absent.

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\* *Trans.*, xxiv., p. 968.

† Van Hise and Hoskins. In "Principles of Pre-Cambrian Geology," 16th *Ann. Rept. U. S. Geol. Surv.*



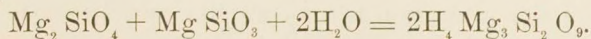
*Calculation of Analyses.*

In order to trace the metasomatic changes by which one mineral has resulted from another, it is necessary to know the composition of each, and the change in volume during the alteration. Without the latter the problem is capable of many solutions, any one of which may be possible, though not true. Only when some definite data, such as the constancy of one constituent, are available, can the changes be determined without reference to relative volumes. For instance, the percentage-composition and specific gravity of argentite and pyrargyrite are as follows:

	S	Ag	Sb	Sp. Gr.
	Per cent.	Per cent.	Per cent.	
Argentite ( $\text{Ag}_2\text{S}$ ), . . .	13.0	87.0		7.0
Pyrargyrite ( $\text{Ag}_3\text{SbS}_3$ ), . . .	18.0	60.0	22	5.8

Pyrargyrite may be altered into argentite; but analyses alone give no complete clue to the character of the alteration. Supposing, however, that we have found that 1000 cub. centim. of pyrargyrite becomes 570 of argentite; then we may calculate that about 9 kilos of sulphur and 22 of antimony have been removed from 100 kilos of pyrargyrite during the process, while the silver has remained constant. Supposing, again, that we have found pyrargyrite altered into argentite without change of volume; then from the original 100 kilos, 2.24 of sulphur and 22 of antimony have been lost, and 44.8 of silver added.

To exemplify further the many ways in which even simple metasomatic problems can be solved, we may take the well-known change of olivine to serpentine, consisting, as ordinarily considered, in a simple hydration of the original mineral. And, in order to simplify the matter still further, we may substitute for olivine the pure magnesium orthosilicate, occurring as a mineral under the name of fosterite, and assume the resulting serpentine to contain no iron. The formulas show that serpentine cannot be derived from olivine or fosterite by means of a simple addition of water. It may, however, be derived from enstatite (which is a magnesium bisilicate) and fosterite, as follows:



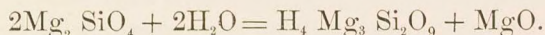
Translated into kilograms, this means that 50.8 kilos of fosterite + 36.2 of enstatite + 13 of water is equal to 100 kilos of



serpentine. This again translated into volumes by aid of the specific gravities, means that 15.8 cb. cm. fosterite + 11.7 cb. cm. enstatite + 13 cb. cm. water is equal to 40 cb. cm. serpentine, or that 27.5 cb. cm. anhydrous silicates are needed to produce 40 cb. cm. serpentine. In other words, the increase of volume during the process of serpentinization amounts to over one-third;—the specific gravity of fosterite being 3.24, that of enstatite, 3.1; and that of serpentine, 2.5.

Serpentine may also be obtained by adding silica and water to fosterite. Thus,  $3\text{Mg}_2\text{SiO}_4 + 4\text{H}_2\text{O} + \text{SiO}_2 = 2\text{H}_4\text{Mg}_3\text{Si}_2\text{O}_9$ . Calculating in the same manner as above, we find that 131 cb. cm. of fosterite results in 221 of serpentine, which represents an increase in volume of somewhat less than one-third.

Still another way of derivation is by subtracting MgO and adding water, as shown by the following formula:



This again is equivalent to the formation of 110.4 cb. cm. of serpentine from 86.3 of fosterite, or an increase of volume of only one-fourth.

Many other formulas could be put forward, which would explain the formation of serpentine, each showing a difference in the relation of volume of the secondary mineral to that of the fresh. Even in this simple case it might be, in any given problem occurring in nature, extremely difficult to decide with confidence which particular formula should be applied. The problem only becomes definite when we positively know the relation of volume of original substance to that of secondary substance. It is perhaps superfluous to add that the mere knowledge of specific gravities does not give this relation of volumes.

When we have to consider metasomatic processes affecting rock-masses, aggregates of from two to six or more minerals, the complexity of the problem becomes immensely greater; for each of these constituent minerals may have suffered different metasomatic changes. Some may have remained unaltered, while others have been completely replaced; and others, again, may have lost, or gained, or exchanged one or more elements. To calculate the sum total of these changes is often an extremely puzzling task.



The mineral composition of the altered, as well as the fresh, rock may be accurately calculated by methods known to petrography, if its analysis, as well as those of the constituent minerals, be available. Even where the latter are only approximately known, a fairly accurate calculation may be made. Thus, for instance, from an analysis of an altered granite containing pyrite, calcite, magnesite, siderite, sericite and quartz, the percentages of these minerals may be obtained with fair accuracy.

The chemical changes suffered during any alteration of a rock may be considered by unit-weight of original substance or by unit-volume of the same. The results will be identical if both rocks are non-porous, or if both have the same porosity. If the actual additions and subtractions should happen to balance, then the percentage-analyses offer, by comparison, direct evidence as to the quantitative alteration. If, besides, during the alteration, the porosity of the two rocks remain the same, then the changes measured by unit-weight will be identical with those measured by unit-volume. This exact balancing of gains and losses, however, is, of course, exceedingly rare. If we do not know the relation of volumes between the two rocks, other ways must be sought for, at least, a partial solution of the problem. If we know that one or more new constituents have been added, we may subtract these, recalculate on 100, and then compare the analyses. This method in many cases leads to fairly correct results; but it must be applied with the understanding that, ordinarily, it will only give approximate results; and that, if there be many partial additions and subtractions, the inaccuracies may be very great, and actual losses and gains may appear reversed.

If we know that one constituent has remained constant, with neither gain nor loss (as the silver in the example cited above), then correct results may be obtained by recalculation on this assumption, as has been shown. This mode of calculation has been used by Scheerer, J. Roth, and lately also by Prof. G. P. Merrill, in his book on "Rocks and Rock-Weathering." It is only rarely, however, that we are able to recognize this constancy; for nearly all constituents undergo some change in the alterations of wall-rocks. Even alumina, often considered to be nearly insoluble, shows great changes in some altered rocks. Besides, if we base recalculation on some compound of which



but a small percentage is present, the multiplication of errors may play havoc with the result. Altogether, this mode of ascertaining gains and losses must be applied with the greatest caution.

Any given analysis of fresh and altered rock may correspond to several very different mineral compositions. For any given mineral composition, the constancy of one constituent during the change to another (also known) mineral composition, determines the change in volume involved (not considering porosity). When the change in volume can be directly ascertained, we are definitely able to obtain the absolute gains and losses suffered by unit-volume of the rock; and this comparison is ordinarily the one which throws most light on the processes involved. But relations of volume are difficult to obtain with certainty, especially in regard to a rock made up of a number of minerals which have suffered different changes. As a rule, in fissure-veins, the replacing minerals are denser than those replaced; so that, if the rock remained compact, there would be a decrease in volume. But as there usually are no indications of compressive stress in the altered rock, the result of this replacement of lighter by heavier minerals will be a porosity expressed by a notable difference in the experimentally determined specific gravity of the rock and that calculated from its known mineralogical composition. This may, in some cases at least, justify the assumption that the rock has not changed its volume as a whole; and if this be true, a direct comparison between equal volumes of fresh and porous altered rock is practicable. Should it appear probable that an actual change of volume has taken place, either by expansion or contraction, it will ordinarily be a difficult matter in each case to ascertain the exact amount of this change, without which knowledge the calculations cannot be carried out. If there is porosity, the changes by unit-weight of original substance may differ greatly from those obtained by unit-volume; hence porosity is a factor which must not be overlooked. One method may indeed indicate the very opposite of the other. For instance, by the first way, it may be ascertained that a rock has gained several per cent. of its weight; while the other method may show that an actual loss per unit-volume of original rock has taken place.



In the considerations outlined above, it is assumed that the rocks to be compared have undergone no change of volume since their removal from the surrounding mass. In regard to the fresh rocks, there is, as a rule, little fear of this. Certain altered rocks, however, easily soften or crumble when exposed to the air, probably indicating that an increase in volume is taking place. An exceedingly slight action of this kind would evidently be sufficient to break up the rock if it were not confined. There is, therefore, little reason to fear that such change of volume has taken place, if the specimens of altered rock remain firm and solid.

*Criteria of Metasomatism.*

Considerable space was devoted to this subject in the discussion of Pösepný's paper in the Transactions of the Institute,\* and it may therefore be passed with brief notice.

It is not always easy to decide whether metasomatic action really has taken place, and in deciding this question the greatest caution must be observed. The mere occurrence of two minerals together by no means proves that one has been derived from the other. The chief difficulty is to draw the distinction between molecular processes involving simultaneous dissolution and precipitation, on the one hand, and previous dissolution and subsequent precipitation on the other.

The only decisive criterion is that of metasomatic pseudomorphism, involving the proof (generally to be furnished by microscopic study) as to whether simultaneous dissolution and deposition have actually taken place. The most satisfactory proof is the distinct alteration of well-defined crystals (or, at least, well-defined grains) of the original mineral into the secondary mineral, in such a way that the latter projects into the former in prisms or fibers, having crystalline outlines. Another proof is afforded by sharply defined crystals of the secondary, embedded in the primary mineral, without any break between their surfaces; but in this case it must be clear that the replacing mineral is really secondary, and was not formed before the primary. Another satisfactory proof is given when, for instance, in a sandstone, the newly formed mineral has in part

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\* *Trans.*, xxiii.



a crystalline form, and its surfaces squarely intersect the grains of clastic material which it partly replaces.

There are many other available criteria such as the enlargement of fissures in the replaced mass. An instance is shown in Fig. 30, representing a veinlet of quartz formed by filling a small open fissure, and adjoined on one side by galena, which extends most irregularly into the adjoining quartzite. (See also Fig. 28.) The retention of the structure of the original mass by the secondary replacing minerals is also an excellent criterion, provided it be identified beyond doubt. Thus, for example, certain porphyritic rocks have suffered nearly complete silicification, but preserve almost entirely the outlines of phenocrysts and the structure of the ground-mass. The occurrence of remaining *nuclei* of unaltered rock is sometimes an available criterion; but it must be used with caution, and probably has given rise to misinterpretations, on account of its similarity to actual inclusions of country-rock in vein-filling. In cases of replacement by sulphides, the unaltered residual rock may be sharply defined, and may closely simulate inclusion. In cases of replacement by calcite or quartz, there is less of this danger, as the action is usually more gradual. If the alteration or replacement proceeds normally from the outside of a crystal or angular mass of rock, the tendency will be towards rounded residual portions in the interior of the mass, as may often be seen in altered crystals of olivine. This criterion for replacement, suggested by Mr. G. F. Becker, may under circumstances prove useful. Generally, however, the replacement proceeds very irregularly, owing to the effect of little cracks and fissures. Slight clay-seams may often interpose an absolute barrier, so that sharp contacts of replaced and fresh rocks result. The replacement of crystals or angular fragments may occur without changing in the least, even by the rounding of corners, the form of the masses.

In conclusion, I would repeat and adopt the statement of Mr. Becker,\* that "the theory of the substitution of ore for rock should be accepted only when there is definite evidence of pseudomorphic, molecular replacement."

In many fissure-veins, practically all of the economically im-

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\* Discussion of Posepny's paper, *Trans.*, xxiii., p. 602.



portant ore has been formed by replacement; and for these deposits the term *replacement-veins* is especially used. But if we do not confine ourselves to the fluctuating definition of "pay-ore," practically all fissure-veins are, to some extent at least, replacement-veins.

Mr. Emmons\* has suggested the following criteria for "*replacement-veins*" in the narrower sense of the word: (1) absence of symmetrical banding or comb-structure in the vein-material, and of breccias of country-rock, cemented by vein-material; (2) great irregularity in the width of the ore-bodies, which may reach very great dimensions; (3) general lack of definition between ore-body and wall-rock.

#### *Crystallization of Secondary Minerals in Other Bodies.*

It has been known for a long time that perfect crystals of minerals, such as quartz, for instance, may be formed in soft rocks such as shale, limestone, clay, etc.; but concerning their exact mode of formation there has been considerable difference of opinion. Probably the prevailing view, some 20 years ago, was that the growing crystal had, by means of its force of crystallization, pushed apart the surrounding mass. This was indeed the opinion of von Groddeck, who declares† that "the formation of a completely developed crystal in a solid, rigid mass is not possible." Apparent exceptions, such as magnetite in chloritic schists, he considers as caused by development, while the rock was soft, under the influence of metamorphic agencies. There is no doubt good foundation for this view; for in magmas and solutions crystals may grow to perfect development, and if, for instance, a saturated solution of ferrous sulphate is mixed with some neutral fine powder to a soft pulp, extremely clear and sharply developed crystals of this salt will separate out.

But it has gradually become apparent that it is not necessary to assume complete permeation and softening of a rock by concentrated solutions, in order to account for secondarily-developed crystals. It is now well known that the secondary development of crystals in solid material is not only a possible

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\* U. S. Geol. Surv., p. 38, on Butte, Montana.

† Die Lehre von den Lagerstätten der Erze, 1879, p. 48.



but an exceedingly common phenomenon, and that it may be caused by simple metasomatic replacement of the surrounding material.

The mechanical force of crystallization probably co-operates, to some extent, with the chemical agencies of replacement; and when the surrounding mass is thoroughly softened and saturated by the depositing solutions, the former force may be alone active. The growing crystal may include parts of the surrounding rock, as is seen in Figs. 3 and 4, representing calcite in quartz, and in Fig. 27, showing inclusions of sericite in pyrite. This is analogous to, but not identical with, the occurrence of inclusions of fluid and glass in crystals separating out from solutions or magmas. It is not uncommon to find new crystals of perfect development generated in a grain of another substance, such as quartz or feldspar, without any disturbance of the optical orientation of the older minerals, such as unfailingly would occur were the process simply one of mechanical force. No doubt the exchange of substance takes place through the medium of a film of water, but this is generally so exceedingly thin that the strongest powers of the microscope fail to reveal it. In many cases, however, the new mineral begins to grow on the planes of small fractures, traversing the original mineral. Fluid inclusions accumulate on this plane; and the first separation of the new mineral appears as little dots, closely connected with the inclusions. No doubt the line between metasomatism and cavities of dissolution subsequently filled is a very fine one, and difficult to draw in many cases; but when intermediate cavities or subsequent fillings cannot be traced with the microscope, the process may be classed as metasomatic; and in the great majority of cases this interpretation will be correct.

#### *Secondary Alteration of Veins.*

Under any given conditions, minerals tend to assume the forms most stable under those conditions. Since the conditions prevailing during vein-formation are very different from those prevailing afterwards, it may be inferred that the products of the first process might easily be changed. Such is indeed the case. We find many altered rocks which have evidently undergone more than one change. Especially near the surface,



under the influence of oxidizing waters, the minerals formed in the rocks along veins are apt to suffer great changes. Examples are frequent, showing that the minerals which filled the open spaces along a vein have been completely dissolved and partly or wholly replaced by others. This is particularly true of fillings of calcite or barite. Many instances are known in which large masses of these minerals have been completely dissolved and replaced by quartz. Such are the well-known deposits of Schneeberg in Saxony, and those of the De Lamar mine in Owyhee county, Idaho.

*Structure and Composition of Metasomatic Vein-Rocks and their Relation to General Metamorphism.*

The aggregates replacing the original wall-rocks of veins show great variety of structure. It is most common, perhaps, that the structure of the resulting rock is much finer than that of the primary. As examples may be cited silicification, which nearly always results in microcrystalline and cryptocrystalline aggregates, and sericitization, which generally results in a mass of very fine tufted fibers. This is not, however, a general rule; because certain easily soluble minerals, when replacing others, produce a much coarser aggregate than that of the original rock. Of such character, for instance, are the carbonates. (See Fig. 27.) Fluorite replacing limestone (see Fig. 14) is another instance of coarser grain shown by the secondary rock.

As a general rule, the resulting minerals have, on the whole, a greater aggregate specific gravity than the original minerals. Muscovite, sericite, fluorite, the different carbonates, pyrite and other sulphides (as well as topaz and tourmaline, so abundantly formed in tin-deposits) are instances. On the other hand, there are exceptions, such as the development of jasperoids and other quartzose rocks from limestone, in which case the resulting material has less specific gravity than the original.

A banded structure of the altered rock may possibly, as mentioned above (p. 13), result from replacement by sulphides in a sheared rock, in which the shear-planes are closely spaced; but this banding is not likely to be as well marked as the crustification often caused by the gradual filling of open spaces. From these two sorts of banding a third must be differentiated, namely, the typical "ribbon-structure" caused by shearing of



the already-formed vein, in connection with which a secondary concentration of gold and sulphides may have taken place on the shear-planes—whence the richness of vein-material often associated with this structure.

In no case, thus far, has any law of progressive alteration of the country-rock of a vein been detected, which would enable us to say that the intensity of the process either increases or decreases from the surface down. Nor has any instance been shown in which the processes of alteration permanently change with increasing depth. This does not exclude the fact that occasionally a different subordinate process of alteration may be introduced. It is known, for instance, that certain parts of the rock near the vein may be locally silicified, although the principal and prevailing process in depth, as well as near the surface, is of a totally different character. Thus, silicification and the formation of greisen may occur side by side in cassiterite veins, and silicification and carbonatization in cinnabar veins.

The metasomatic processes in wall-rocks of fissure-veins differ generally from those of regional (static and dynamic) metamorphism. In most cases oxides of iron and manganese such as magnetite, hematite, ilmenite and pyrolusite, are absent as a primary development; and many silicates, exceedingly common in static and dynamic metamorphism are, as a rule, missing in veins. Among these are amphibole, biotite, garnet, cordierite, serpentine, ottrelite, and zoisite. Chlorite and epidote are confined to the vicinity of only one or two classes of veins. Albite, exceedingly common in regional metamorphism, is not known as a metasomatic development on veins, though, like orthoclase, it may occur in the filling of open cavities. Muscovite, calcite, quartz and pyrite are common to both kinds of metamorphism. As compared with the products of contact-metamorphism, we note in metasomatic vein-phenomena a total absence of the pyroxenes, wollastonite, staurolite, cyanite, andalusite, vesuvianite and garnet. Only two classes of veins are characterized by tourmaline, which is a frequently occurring contact-mineral. Again, as compared with the results of ordinary hydro-metamorphism, we note in the results of metasomatic vein-action the total absence of amphibole as well as of zeolites, except in one or two classes of veins, and also the relatively slight importance of chlorite and epidote.



The degree of hydration in altered vein-rocks is very moderate; and in some cases, as, for instance, in the change of serpentine to magnesite, there is a distinct dehydration. Strongly hydrous minerals are not common on fissure-veins.

I have emphasized these differences, to show that the metasomatic processes in veins cannot simply be identified with those that were active in the other phases of metasomatism mentioned. In the majority of cases, the vein-processes have a distinctive character of their own.

## PART II.

### MINERALS DEVELOPED BY METASOMATIC PROCESSES IN FISSURE-VEINS.

*Quartz (including Chalcedonite and Opal).*—Though silicic acid is weak, and cannot under ordinary circumstances expel even carbonic acid from its compounds, it is easily deposited instead of other minerals, which are dissolved by more active reagents contained in the same waters. Hence the frequency of quartz in the forms of other minerals. It would be erroneous to say, however, that silicification is a very common metasomatic process, even in veins containing quartz as a filling; and very rarely is it the exclusive process in any given vein. It is most common in limestone and other easily soluble rocks; also in such porous rocks as sandstones, though here it is usually to be regarded rather as cementation. In rocks rich in silica, such as rhyolite or quartzite, the tendency to silicification (probably by reason of mass-action) is greater than in more basic rocks in the same district.

Quartz replacing limestone along fissures is a common occurrence. The process usually results in a microcrystalline or cryptocrystalline aggregate of interlocking grains; preserving the original structure, as shown in Fig. 1,\* which represents a silicified limestone from the Diadem lode, Plumas county, Cal., and shows the remaining outline of a foraminiferal test. The development of the quartz is shown in Figs. 3 and 4,† represent-

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\* After H. W. Turner, *Journal of Geology*, vol. vii., No. 4.

† The accompanying figures, with some exceptions noted in the list, were drawn by myself under the microscope, with camera lucida.



ing rocks from Aspen, Colorado.\* Small secondary grains or well developed crystals appear in the limestones and, gradually extending, finally produce an aggregate which, in this case, is somewhat coarser than in the rock from California. Quartz crystals with double terminals may occur in metasomatic rocks, but are foreign to quartz, filling open cavities. Opal and chalcedonite may occasionally also be present.

The resulting fine-grained rocks, often stained brown or red, may, according to Mr. Spurr's proposal, be called jasperoids. Daubrée describes heavy quartz veins, cutting through granite and overlying sedimentary rocks, in the Central Plateau of France.†

Besides quartz, these veins carry fluorite, barite, calcite and galena. Agate and jasper in banded form are also frequently present. From the same description,‡ it appears that in some places, where these veins traverse limestone (*Muschelkalk*), there has been a very strong silicification of the enclosing rock, as is proved by means of the occurrence of crinoids in the compact quartz now forming part of the lode. Another locality, also in the Vosges, is mentioned as showing a large deposit of fine-grained hornstone-like quartz, also containing barite and fluor-spar, and full of little geodes with projecting crystals of quartz. In this siliceous rock, silicified shells of *avicula* and *pecten* have been found, showing its derivation from the surrounding limestone. The chemistry of the process is apparently simple: waters containing carbon dioxide and silica deposit the latter, while simultaneously dissolving a corresponding proportion of calcite.

In contrast to the fine-grained structure of jasperoids, quartz deposited in open spaces is usually characterized by coarse grains, the majority of which show partly developed crystal-faces. Crystals developed at both terminals do not appear, though earlier-developed individuals, growing from some deposit, are surrounded by later-developed grains. Fig. 2, which shows the normal structure of the quartz in the California gold-veins, illustrates this occurrence.

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\* The thin sections from which these figures were made were kindly loaned to me by Mr. J. E. Spurr.

† Daubrée, *Les Eaux Souterraines aux Epoques Anciennes*, p. 124.

‡ *Loc. cit.*, p. 151.



Quartz may further replace orthoclase, as shown in Fig. 5, with preservation of the crystal-form. The ordinary course of alteration of the latter mineral is to quartz, sericite, or kaolinite, and potassic carbonate. In complete replacement by quartz, the alumina and potassa have been carried away, and the quartz has received a considerable addition. The process may also be explained as a complete replacement, by means of which the orthoclase, as such, has been removed, and quartz has been deposited. In the same manner, soda-lime feldspars may be replaced by quartz, as well in phenocrysts as in the ground-mass. Even the ferromagnesian silicates may suffer a similar change. A partial replacement of hornblende by quartz and chlorite (Fig. 6) is common. The ground-mass surrounding crystals of quartz in certain rhyolites (Silver City and De Lamar, Idaho) may be replaced by quartz, forming a secondary aureole around the primary crystal.

Under favorable and very exceptional circumstances, veinlets containing coarser quartz, simulating comb-quartz in structure, may be formed by replacement. Fig. 7 represents a contact between chloritic basalt and silicified rhyolite, on which a small quartz vein is developing, the crystals replacing the ground-mass of the silicified rhyolite.\* Replacement of minerals by chalcedonite and opal instead of by quartz is less common. Near cinnabar veins, in California and elsewhere, serpentine, transformed into opal, with retention of the primary structure, has been observed.

*Rutile and Anatase.*—These minerals are common in metasomatic vein-rocks, as secondary products after ilmenite, titanite, titaniferous magnetite, biotite, etc. Rutile occurs in nearly every altered titaniferous rock; anatase (octahedrite) has been found in the altered rocks of Freiberg (Stelzner), Nagyag (Kollbeck), Schwartzwald (Sandberger), and Silver Cliff (Cross). Neither titanite nor ilmenite appear to be stable under the influence of vein-forming solutions. In several publications† I have assumed that the milky white flocculent mass (leucoxene) which often results in vein rocks from the alteration of titaniferous minerals is titanite; but this assumption now appears to

\* 20th Ann. Rept. U. S. Geol. Surv., part iii., p. 186.

† 14th Ann. Rept. U. S. Geol. Surv., part ii., p. 150, *et seq.* 17th Ann. Rept. U. S. Geol. Surv., part ii., p. 277, *et seq.*



be incorrect. The substance is certainly free titanitic acid, as shown by the fact that no titanium is extracted by hydrochloric acid, while the mineral is attacked by boiling sulphuric acid.

*Fluorite*.—This mineral may replace many others. It has generally a purplish, unevenly distributed color, and shows under all circumstances a strong tendency to crystal-development. Its formation from limestone is illustrated in Fig. 14, which represents the contact of one of the many small nodules of fluorite scattered in a limestone breccia from near the Spotted Horse mine, Judith mountains,\* Mont. The sharp angles of the cube will be seen projecting into the limestone; the latter contains many imperfect fossil shells, and some crystals of secondary quartz.

While the reaction involved in this process is not clearly established, it is probably a complete replacement, the more soluble calcite being taken up by the waters and the less soluble fluorite simultaneously deposited.

Fluorite, together with quartz and pyrite, is further formed as a replacement-product of orthoclase, as shown in Fig. 10, representing a feldspar grain from a breccia in the Independence mine, Cripple Creek, Colo. The replacement of some of the phonolite and fine-grained granite-andesite breccia from Cripple Creek has resulted in a large quantity of crystalline fluorite and quartz (Fig. 9). Wherever calcium silicates are present, and the waters contain sodic fluoride, the result will be sodic silicate and calcic fluoride. In this way the mineral may be formed by interchange of constituents.† Alkaline fluorides and calcic fluorides may exist together in the same solution; but alkaline carbonates decompose fluorite, yielding alkaline fluorides and calcic carbonate; hence fluorite cannot exist as such in waters containing alkaline carbonates.

*Calcite*.—This mineral and the allied magnesian and ferrous carbonates are exceedingly common in metasomatic vein-rocks, and their occurrence gives testimony of the energetic altering action of carbon dioxide and alkaline carbonates on nearly all silicates. The metasomatic calcite is of fine or coarse grain—the latter especially when replacing easily soluble minerals. It

\* This section was prepared for Mr. W. H. Weed, who kindly allowed me to use it.

† Bischof, *Chem. Geol.*, Bonn, 1864, ii., p. 64.



has very little tendency to crystallize, nearly always occurring in irregular grains.

Calcite replaces quartz to a greater or less extent, though in rocks containing also silicates like feldspars and hornblende, these minerals are first attacked, and the replacement of the quartz is usually only partial. The quartz is evidently dissolved by waters containing alkaline carbonates, and a corresponding quantity of calcic carbonate, also dissolved in the water, is deposited in its place. Under ordinary pressure and temperature, water does not dissolve quartz; but increase of either results in solution to some extent. The presence of carbon dioxide alone does not promote the solubility. No pseudomorphs of calcite after quartz are known—an evidence of the resistance of the latter mineral to solution.

The replacement of quartz by calcite in granitic rocks is shown in Figs. 13 and 15. The calcite, developed along cracks and fissures, spreads and corrodes the original substance. Small masses of sometimes rhombohedral calcite project into the quartz. Rounded and isolated bodies of calcite may also form on inclined fracture-planes; by extension they finally join and form larger masses.

Orthoclase is likewise replaced by calcite in many granitic rocks adjoining veins. The process is similar to the replacement of quartz; but the feldspars are much more easily soluble than quartz. Chemically, the process, as already pointed out by Bischof,\* may be considered as simply due to the attack of waters containing calcic bicarbonate. The carbon dioxide of the latter alters the orthoclase; the resulting alkaline carbonates and silica are carried away; just in what form the alumina is removed is not certain. In the majority of cases a simultaneous formation of sericite occurs; so that the actual loss of  $\text{Al}_2\text{O}_3$  may be very small. Even more easily effected is the replacement of soda-lime feldspars by calcite; for here the original mineral contains one of the constituents of the result. As is well known, andesine, labradorite and anorthite may be partly converted into calcite under the influence of ordinary cold waters containing carbon dioxide.

In the same manner, it is common to find pyroxene, amphi-

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\* *Chem. Geol.*, ii., p. 428.



bole and biotite partly converted into calcite. In vein-forming processes, these are usually the first minerals to suffer from the attack. The magnesia, alumina and ferrous oxide usually remain in the form of chlorite or other secondary silicates, though some of the magnesia and iron may also form carbonates.

*Magnesite and Dolomite.*—Small quantities of magnesian and ferrous carbonates nearly always combine with the newly formed calcite, but in many cases are of no special importance.

A change of limestone to magnesite is not known as a vein-forming process. Dolomitization commonly occurs, however, in limestones adjoining fissure-veins, as, for instance, described by Spurr\* at Aspen, Colorado. At this place, as the dolomitization proceeds irregularly from the fissures, the coarse calcite grains are broken up into smaller rhombohedral crystals, of the yellowish tinge characteristic of dolomite. The process is clearly one of metasomatic replacement, carried on by waters containing magnesian bicarbonate, or even chloride. The correctness of this view has been shown by synthetical experiments.†

Mr. Spurr shows convincingly that ordinary circulating surface-waters do not dolomitize the limestone which they traverse. The reagents which produced this dolomitization must have been more potent. Several hot springs in the vicinity of Aspen, Colorado, carry carbonates of lime and magnesia, and also a large amount of sodium chloride and magnesium chloride. These waters, as shown by analyses, have a distinct dolomitizing influence on the adjoining limestone. The change is also accompanied by silicification and ferration.

Dolomitic carbonates may also partly replace albite, as shown by Mr. H. W. Turner‡ in the case of a mineralized dike of albite rock from Tuolumne county, Cal. An accompanying almost pure magnesite may possibly have resulted from the alteration of the adjoining serpentine.

Magnesite and dolomitic carbonates are very apt to form from serpentine, as illustrated in the country-rock adjoining the Idaho vein, Grass Valley, Cal.§ The fine-grained serpentine is trans-

\* Monograph XXXI., *U. S. Geol. Surv.*, p. 210.

† Doelter, *Allgemeine Chemische Geologie*, Leipzig, 1900, p. 158.

‡ *Journal of Geology*, vol. vii., No. 4.

§ W. Lindgren, 17th Ann. Rept. *U. S. Geol. Surv.*, part ii., p. 153.



formed into a coarse-grained magnesite, mixed with quartz and some residual serpentine (Fig. 26). The composition of the altered rock is

	Per cent.
Magnesian carbonate, . . . . .	34.78
Calcic carbonate, . . . . .	8.22
Quartz, . . . . .	26.00
Serpentine (with chlorite), . . . . .	31.00
	<hr/> 100.00

The chemical action involves a substitution of  $\text{CO}_2$  for  $\text{SiO}_2$ ; the latter being deposited in the rock.

*Siderite*.—This mineral is less common in altered rocks than the other carbonates. At Aspen, Colorado, Spurr mentions it as forming small rhombohedrons in silicified limestone. In the lead-silver veins of Wood River, Idaho, it replaces calcareous shales. In the lead-silver veins of Cœur d'Alene, Idaho, it replaces the clastic quartz of quartzite in the most energetic manner and abundant quantity (Figs. 16 and 17). The siderite has strong tendency to crystal development; and the rhombohedral crystals often cut squarely across the quartz grains which they partly replace (Fig. 18). To explain the chemistry of this process, we must suppose waters exceedingly rich in alkaline and ferrous carbonates and poor in silica.  $\text{SiO}_2$  must be dissolved and  $\text{FeCO}_3$  simultaneously deposited.

*Muscovite and Sericite*.—These two names practically signify the same mineral, though sericite is employed for the fine-grained or fibrous and tufted modifications, resulting from the replacement of other minerals. Sericite is probably the most universal and abundant of all minerals forming in altered rocks near fissures. Only a few classes of ore-deposits, namely, those in limestone and those in recent volcanic rocks, involving propylitic alteration, are comparatively free from it. A vast proportion of so-called "talc," "clay" and "kaolin" is really sericite.

Sericite forms from quartz in many rocks, though this action is less intense than in the case of the silicates. Foils and fibers of the secondary mineral may develop along cracks, or may intrude, sharply defined, into the quartz, from the outside of the grain. Complete pseudomorphs after quartz are rare. A complex chemical action is probably involved, as sericite is practi-



cally insoluble. A transportation of potash and alumina must be assumed, though in what form the latter oxide was in solution is not clear. The dissolved quartz may be directly combined with these two constituents. It is often observed that the replacement of the quartz is most active when, together with the sericite, calcite is formed (Fig. 15).

As is well known, sericite forms easily and abundantly from orthoclase and microcline, the foils and fibers developing on cleavage-planes and cracks, until they invade the whole crystal. The reaction may be chemically expressed as follows, water containing carbon dioxide being the only reagent necessary:



This reaction is accompanied by a considerable reduction of volume, the sericite occupying less than one-half of the original volume of the orthoclase. If  $SiO_2$  separates as quartz, the aggregate volume of the two secondary minerals shows a reduction of 13 per cent. from the volume of the orthoclase. Very often, however, the quartz is carried away in solution, to be deposited in neighboring open spaces. Calcite is frequently deposited together with sericite in the feldspar (Fig. 12). Though it is usually fine-grained, large foils may sometimes be formed. Fig. 19 shows radial muscovite forming, together with kaolinite from orthoclase, in the orthoclase of granite adjoining a fissure, in which thermal waters at the present time are depositing a vein.\*

Sericite forms with equal ease from oligoclase, andesine and labradorite, as from orthoclase, and calcite usually also accompanies it. This interesting fact was first described, I believe, by Bischof,† who also furnished the chemical explanation. The potassic carbonate contained in the water changes the sodic silicate into potassic silicate, which unites with the aluminum silicate to sericite. This will result in a progressive elimination of soda and introduction of potash. In the same manner potassic carbonate decomposes calcic silicate, replacing lime with potash. Bischof gives an excellent illustration of this by describing the surface alteration of a knife of the "stone age," originally made from some flinty rock.

\* W. H. Weed, *Trans.*, Washington Meeting, Feb., 1900.

† Bischof, *Chem. Geol.*, i., p. 31, *et seq.*; also p. 44.



Even pyroxene and amphibole may alter to sericite, as is frequently shown in the metasomatic vein-rocks of California gold-quartz veins. The explanation is on the lines of the reactions just described. The resulting sericite is often coarsely fibrous.

Biotite alters very easily to coarse muscovite, with loss of magnesia and iron, and separation of rutile (Fig. 27).

An instance of replacement of andalusite by muscovite is shown in Fig. 20. Few analyses are available, indicating the exact composition of the sericite contained in metasomatic vein-rocks; but the satisfactory results obtained from the calculation of many rock-analyses on the basis of molecular ratio, closely corresponding to the composition given below, leave little room for doubt that the sericite is practically identical in composition with a normal muscovite.

Prof. Beck, of Freiberg, has had the kindness to give me an unpublished analysis, made by Dr. H. Schulze, of a white mica, separated by Prof. Stelzner by heavy solutions from the altered country-rock adjoining the Dietrich Stehenden, Morgenstern Erbstolln, Himmerlfahrt mine, Freiberg. This analysis is as follows:

	Per cent.
SiO <sub>2</sub> , . . . . .	47.48
TiO <sub>2</sub> , . . . . .	trace
SnO <sub>2</sub> , . . . . .	0.02
Al <sub>2</sub> O <sub>3</sub> , . . . . .	35.16
Fe <sub>2</sub> O <sub>3</sub> , . . . . .	1.92
CaO, . . . . .	0.48
MgO, . . . . .	1.11
K <sub>2</sub> O, . . . . .	10.08
Na <sub>2</sub> O, . . . . .	0.41
H <sub>2</sub> O, . . . . .	4.02
	<hr/> 100.68

As minerals most closely related to muscovite, we may mention zinnwaldite, containing much fluor and lithia, which replaces feldspar in granite near cassiterite-veins; also mariposite (fuchsite), containing chromium, which, with magnesite, apparently replaces serpentine and allied rocks at Nevada City, and on a much larger scale at many places along the Mother Lode of California.

*Biotite*.—Exceedingly common in the form of metamorphism, biotite appears but rarely in fissure-veins. Replacing horn-



blende and feldspars, it is found as small scales in veins carrying tourmaline (Meadow Lake, Cal.); replacing the same minerals, it appears abundantly in the gold-copper veins of Rossland, B. C. A greenish mica, probably biotite, occurs, replacing quartz, in small veinlets, associated with quartz, garnet, tourmaline, actinolite and zinc-blende, in the Bunker Hill and Sullivan mine, Idaho. Prof. Penrose reports secondary biotite forming in the Ocean Wave mine, Cripple Creek, Col. Under the influence of waters containing carbon dioxide or alkaline carbonates, biotite is not stable.

*Chlorite*.—This mineral, replacing amphibole, pyroxene and biotite, is commonly found in altered vein-rocks, but ordinarily it is only a transition-form, often abnormally rich in iron, which these minerals assume, under the influence of waters slightly charged with carbon-dioxide, before their final conversion into sericite and carbonates. The chlorite has the ordinary fine fibrous character and shows a strong tendency to migrate into adjoining minerals. In the case of biotite, the conversion should normally result in chlorite, ferrous carbonate, potassic carbonate and silica; in that of amphibole or pyroxene, calcic carbonate may form beside chlorite. Pseudomorphs of chlorite and quartz after hornblende are, in fact, very common (Fig. 6). The chloritic alteration is most important in the group of the propylitic veins. Under the influence of strong alkaline carbonates and carbon-dioxide, chlorite can probably not exist. G. F. Becker mentions chlorite as enclosed in vein-quartz from some localities in the Southern Appalachians, and also in gold-quartz veins from Funter's Bay and Admiralty Island, Alaska. I have described a similar occurrence in an abnormal vein, from Crown Point mine, Grass Valley, Cal. But, on the whole, it is not a common mineral in vein-fillings.

*Pyroxene and Amphibole*.—These minerals are, as a rule, foreign to fissure-veins. Amphibole occurs as an accessory in the filling of a few veins, probably formed under special dynamic conditions, as, for instance, in the Rossland, B. C., copper-veins, and in small veinlets of abnormal character, also containing garnets, in the Bunker Hill and Sullivan lead-silver mine, Idaho. Rhodonite, a bisilicate of magnesia allied to pyroxene, does, however, occur on many veins as part of the fill-



ing (Butte, Montana; Real del Monte, Mexico; Kapnik, Hungary; Broken Hill, Australia).

*Garnet.*—This mineral is very rare in fissure-veins, though common in dynamic and contact-metamorphism. Mr. S. F. Emmons\* states that it replaces limestone at Clifton, Arizona, apparently as a part of the phenomena of mineralization. As part of the filling of gold-quartz veins, it is reported by Mr. G. F. Becker,† from several localities in the Southern Appalachians. The remarkable occurrences of Broken Hill, N. S. W., should be mentioned here. From the extensive literature‡ it is apparent that opinions differ somewhat widely with regard to these interesting deposits.

The deposits of the Barrier ranges near Broken Hill are probably fissure-veins, occurring in crystalline schists of various kinds, perhaps chiefly a garnet-gneiss. Broken Hill Proprietary lies parallel to the schistosity, and may, according to some, be considered as a saddle-reef. Other veins, such as the Broken Hill Consols, cut the schistosity in strike and dip. The ores are galena, zinc-blende and rich silver-ores. The gangue in the Proprietary mine is chiefly garnet, with quartz, opal and rhodonite. In the Consols and other veins, siderite and calcite also appear, besides quartz and garnet. If veins, as seems most probable, they represent a decidedly novel type. The sulphides, to some extent, replace other minerals. (See under *Galena*, below.)

*Epidote.*—This mineral, so common in regions of static and dynamic metamorphism, is not abundant in the altered rocks of fissure-veins, or in the filling of open spaces. When it occurs, it has a deep yellow color, contains much iron and develops in irregular grains, or into radial bunches of imperfect crystals. It occurs chiefly in basic rocks containing labradorite and similar soda-lime feldspars, and may form pseudomorphs after orthoclase, plagioclase, hornblende or augite. In altered vein-rocks, epidote and muscovite rarely occur together. Epidote contains much ferric oxide, and can hardly be formed under strong reducing influences. It does, however, not follow

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\* Unpublished observations.

† 16th Ann. Rept. U. S. G. S., part iii., p. 274.

‡ J. B. Jaquet, *Mem.* 5, *Geol. Surv. of N. S. Wales*, Sydney, 1894; George Smith, *Trans.*, xxvi., 1896; R. Beck, *Zeitschr. f. prakt. Geol.*, March, 1899, etc.



that it must have been formed under oxidizing conditions; for rocks ordinarily containing much ferric oxide and pyrite has often been observed embedded in epidote. Epidote is found in the veins of Lake Superior which carry native copper; in some veins characterized by tourmaline (Fig. 21); and, finally, in the metasomatic rocks accompanying the porphyritic Tertiary gold-silver veins.

*Orthoclase*.—As a product of thermal alteration, orthoclase does not commonly appear, and has not been recognized until lately. Closer search will probably reveal it in many altered rocks and vein-fillings of the propylitic type. When forming, it has always a strong tendency to crystallize, and in thin sections usually appears with rhombic, sharply defined outlines. The crystal form is similar to that of adular, though the basal plane is small or entirely wanting; the prisms and dome being the only prominent faces. For this variety, occurring in fissure-veins, the revival of the name of valencianite is suggested, proposed by Breithaupt for the mineral as occurring in the Valenciana silver-mine, Guanajuato, Mex. In certain propylitic gold-silver veins (Silver City, Idaho; La Valenciana, Mex.) valencianite is prominent as part of the filling of open spaces. In the copper-bearing veins of Lake Superior, orthoclase replaces prehnite, and is deposited on datolite, calcite, analcite and quartz. In connection with the occurrence of adular at St. Gotthardt, this mineral is found on calcite. At Bergen Hill, N. J., the Mesozoic diabbases are traversed by veins (1 to 4 inches thick) of quartz and orthoclase, associated with various zeolites, galena, chalcopyrite and pyrite. At Cripple Creek, Colo., orthoclase is an important vein-mineral, occurring partly as a coating of cavities of dissolution in granite (Fig. 11), partly in metasomatic development after many minerals in granite-andesite breccia and phonolite. Orthoclase and calcite have apparently been formed together in certain metasomatic rocks from Cripple Creek, Colo.

Orthoclase has been reproduced artificially by the action of potassic silicate on muscovite at  $500^{\circ}$  C., but it is evident from many occurrences that a much lower temperature is sufficient for its formation in fissure-veins. In the Silver City, Idaho, veins, for instance, the temperature cannot have been much higher than  $100^{\circ}$  C. during the deposition of the mineral.



*Albite*.—Though known as a vein-filling, together with quartz, at many places, for instance, in many California gold-quartz veins, this mineral has not been observed hitherto replacing other substances. In metasomatic rocks resulting from other metamorphic processes it is, as is well known, very abundant.

*Tourmaline*.—This very complex silicate of alumina, magnesia, ferrous oxide and soda contains also about 10 per cent. of boric acid, as well as a little combined water and fluorine. In metasomatic development, it forms irregularly massed crystals, or single crystals impregnating the mother-mineral. Its tendency to crystallization is very strongly marked. It replaces orthoclase and plagioclase, as well as quartz, but is not known to be formed from ferromagnesian minerals. As shown in Fig. 21, small almost perfect crystals may develop in the feldspathic substance, without disturbing its optical orientations. Similar development in quartz is illustrated in Fig. 23. In fine-grained elastic rocks like slate, tourmaline may also form. The only occurring variety is black, usually showing dark brown and dirty bluish or greenish colors in thin section. Tourmaline often occurs in large masses of small felted individuals, together with quartz, entirely replacing the original rock.

The mineral is confined to cassiterite-veins and to the allied group of the gold-copper-tourmaline veins. It is not usually associated with carbonates; and the occurrence of siderite with tourmaline, described by von Fricks from Tasmania,\* is therefore of special interest.

*Topaz*.—This fluosilicate of aluminum, containing besides, according to the latest investigations, some chemically combined water, is confined to the cassiterite-veins. It usually appears abundantly in the altered rock next to these veins, replacing the feldspar and even the quartz,† as well as the groundmass of porphyritic rocks. The new-formed topaz may appear in irregular grains, but is often partly crystallized, and then appears in radial masses. The formation of topaz from orthoclase is analogous to kaolinization, silica and potassa being set free. But fluorine is also introduced, which points to another agent than carbon dioxide as active in this reaction. It has been artificially reproduced by the action of hydro-

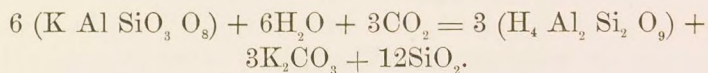
\* *Zeitsch. d. d. Geol. Ges.*, Bd. li., p. 443, 1899.

† *Loc. cit.*



fluosilic acid on silica and alumina. Topaz is not very stable. It is easily altered to kaolinite or sericitic minerals.

*Kaolinite.*—The hydrous silicate of aluminum was formerly supposed to occur very extensively in altered vein-rocks; but it has been shown that the larger part of the minerals considered as kaolinite or as "talc" are really sericite in finely divided form. Kaolinite forms from orthoclase, albite or soda-lime feldspars, with liberation of silica, the reaction in the first case being expressed as follows:



Ferromagnesian silicates, and even quartz, may be converted into kaolinite, as is shown by the altered rock adjoining a recent vein near Boulder, Montana. The mineral is nearly always in an extremely fine state of distribution; the aggregates have a very low bi-refracting power. Kaolinite and sericite may form together (Fig. 19), as is also shown by the calculated composition of many altered rocks. Wherever abundant carbonates form, metasomatically, together with sericite, kaolinite seems to be absent. It often occurs on cassiterite-veins (though it is possible that the kaolinite may here be simply a secondary alteration of topaz); further, together with sericite, in veins of the pyritic galena-formation of Freiberg; in some veins of propylitic character, as at Cripple Creek, and in veins where the action of stronger reagents, such as sulphuric acid, seems probable (Summit District, Colo.,\* De Lamar, Idaho†). Kaolinite is formed most abundantly in the upper, oxidized zones of many ore-deposits.

*Zeolites.*—These hydrated minerals are almost completely absent from fissure-veins. Exceptions are the silver veins of Andreasberg in the Hartz, and Kongsberg in Norway, where many zeolites occur as vein-filling with quartz and calcite. As metasomatic minerals, they occur in the Lake Superior copper-veins replacing feldspars and other minerals. Daubrée has described zeolites forming in old bricks at Plombières, by the action of thermal waters ascending on a vein which does not contain any

\* R. C. Hills, *Proc. Colorado Sci. Soc.*, vol. i., p. 21.

† W. Lindgren, *20th Ann. Rept. U. S. Geol. Surv.*, part iii.



of these minerals. W. H. Weed describes stilbite with quartz as filling of a recent vein by ascending hot waters at Boulder, Montana.\* The absence of the zeolites from veins is somewhat difficult to explain, as it is well known that many of them may be formed at very widely differing pressure and temperature. Very slight modifications of condition may result in the formation of hydrous or anhydrous minerals. Thus, for instance, Friedel and Sarasin† found that when a solution of silicate of soda mixed with silicate of aluminum, in proportions required to form albite, was heated to 500° C. in a closed tube, analcite was formed. When excess of the alkaline silicate was used, albite resulted.

*Pyrite.*—Of all the sulphides occurring as metasomatic minerals pyrite is naturally the most common. In most fissure-veins, it impregnates the adjoining rock in varying amounts, even if the alteration in other respects has not progressed far. The mineral has a remarkable tendency to crystallization when developing in the rock, as contrasted with its often massive texture when occurring as a filling of open spaces. The forms assumed are either cubes or pentagonal dodecahedrons, or a combination of both.

Pyrite develops in nearly every one of the ordinary constituents of rocks. By preference, it forms in the new aggregates of sericite, carbonates and chlorite so common in altered rocks; but it also occurs in the fresh original minerals of the rocks, as in quartz, feldspar, hornblende and pyroxene. It is also abundant in calcareous shales adjoining veins. It is common to find small, sharp crystals embedded, for instance, in perfectly clear quartz grains, which show no break in their optical orientation around the secondary crystal, proving that the genesis is by purely metasomatic processes, and not, as may be advocated in the case of crystallization in soft aggregates, by the mechanical pressure of the growing crystal. On the other hand, the development of a larger crystal in quartz or feldspar will often produce a breaking-up of the grains as an optical unity, and the substitution for it of an interlocking aggregate of smaller grains. To what force this is due is not certain; there are usually no indications of direct pressure from the growing crystal.

\* *Trans.*, February, 1900.

† *Comptes rendus*, July, 1883.



The pyrite crystals are often bordered by a small rim of calcite or quartz; and little bunches of sericitic fibers may adhere to them, when forming in quartz. On the whole, the pyrite seems to obtain some, if not all, of its iron from the ferro-magnesian minerals, rather than from the magnetite and titaniferous ores, which appear to alter to carbonates and rutile.

*Marcasite*.—In metasomatic development, this mineral is rare, though it has been observed accompanied with kaolin, at De Lamar, Idaho, as the result of the hydrothermal alteration of rhyolite.\* It is always crystallized, and the individuals combine to arborescent forms.

*Chalcopyrite*.—This mineral is not common in the metasomatic rocks of gold- and silver-veins, but it forms abundantly in certain replacement-veins, such as those of Butte, Mont., and Rossland, B. C. In such cases, it may replace any of the ordinary rock-forming minerals. It forms in irregular masses, is rarely crystallized, and is frequently accompanied by a narrow lining of chlorite.

*Arsenopyrite*.—Like pyrite, arsenopyrite nearly always forms in crystals; these show the simple combination of rhombic prisms and striated dome, and may also replace any of the rock-forming minerals. Next to pyrite it is the most common sulphide in the altered rocks adjoining veins.

*Pyrrhotite*.—This mineral is not abundant either in vein-filling or in metasomatic rocks. Indeed, in many classes of veins it is entirely absent; and if it happens to be present in the rock close to the vein, it may suffer alteration to pyrite under the influence of the vein-forming agencies.† As a product of replacement of feldspar and ferro-magnesian silicates, it occurs in the Rossland veins of British Columbia, associated with chalcopyrite. The conditions governing the formations of pyrrhotite are not fully known. It has been artificially reproduced, but not under conditions which seem analogous to those of nature. At any rate, the mineral can only be formed under very strongly reducing influences.

*Galena*.—By preference, galena replaces calcite and dolomite. Hence the great abundance of metasomatic galena-deposits in

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\* 20th Ann. Rept. U. S. Geol. Surv., part iii., p. 169.

† 17th Ann. Rept. U. S. Geol. Surv., part ii., p. 147.



limestone, calcareous shale and similar rocks. In crystalline igneous or metamorphic rocks, it is not abundant as a metasomatic product. But it may replace other minerals, especially quartz. Metasomatic galena scarcely ever appears in crystalline form, but often forms wiry, extremely irregular masses. Fig. 25 shows its appearance in primary quartz of a quartz-diorite. It only occurs in quartz which is completely filled with fluid inclusions; and its growth begins as little knots and particles, dotted over any given plane of fluid inclusions. These dots, of which some are shown in the figure, finally appear to have united to larger masses. The quartz grain in which the galena occurs is partly broken up into new quartz aggregates. Galena replacing quartz in quartzite from Northern Idaho is shown in Fig. 16. Gradually extending, the galena unites to larger masses, as illustrated in Fig. 17.

The replacement of calcite by galena is illustrated by Fig. 29, representing part of a section from the Elkhorn mine, Montana, which Mr. W. H. Weed kindly put at my disposal. The rock, a crystalline limestone, apparently free from organic matter, contains small, partly idiomorphic quartz grains, scattered among the larger grains, and also many small veinlets of secondary quartz. There is thus at least an incipient silicification accompanying the formation of the galena. In the little quartz veins and throughout the rock are small, sharply defined pentagonal dodecahedrons of pyrite, nearly always connected with small quartz grains. The galena appears in several smaller grains closely intergrown with pyrite; also in larger masses surrounded by a narrow rim of pyrite, and by clusters of small secondary grains and crystals of quartz. The galena is not clearly crystallized, but appears in small, solid masses, developing along the cleavage planes of calcite so that rhombohedral grains of the latter may be almost surrounded by galena.

Concerning the chemical reactions involved in the replacement by galena opinions differ. Some think that the slightly soluble sulphate of lead is reduced from solutions by organic matter—and adduce as confirmation the universal occurrence of galena in limestone or other sedimentary rocks, presumably containing organic matter. Another view is that, the sulphide of lead being soluble to a considerable extent in water containing sodic sulphide (Doelter), a simple precipitation from solu-



tion has taken place, dependent on the simultaneous solution of limestone and separation of silica.

For most cases I would be inclined to the latter view, since the small quantity of organic matter available, for instance in the Elkhorn limestone or in the Cœur d'Alene quartzite, seems utterly insufficient to reduce such large masses of galena as are found at these localities. Besides, silver-lead veins may occur in the same districts in very different rocks. Thus, for instance, in the Wood River region, Idaho, they are found not only in the limestone but also in granite, which certainly does not contain organic substances.

In this connection should be mentioned the replacement of rhodonite by galena and zinc-blende, described and figured from Broken Hill, Australia, by Prof. R. Beck. From the same locality Mr. Jaquet described and figured galena replacing orthoclase; and a silver mineral, probably argentite, replacing garnet, and perhaps quartz, in a garnet schist.

*Zinc-blende and Other Sulphides.*—In metasomatic occurrence zinc-blende is extremely similar to galena. It is usually found as irregular grains, never as crystals, replacing limestone, quartzite (Fig. 17), and many minerals in igneous rocks.

Much additional material might be quoted regarding the replacement of rocks by other sulphides; the literature on the subject should be used, however, with care, since critical studies of the modes of replacement are very few, and some statements are simply based on casual inspection with the naked eye.

Many other sulphides are undoubtedly formed by metasomatic replacement. Enargite, for instance, is noted by Emmons\* as replacement thus present in the altered vein-rock of Butte, Mont.

*Tellurides.*—Tellurides of gold and silver are found at Cripple Creek and elsewhere, under circumstances indicating metasomatic deposition.

*Native Copper.*—This metal replaces many minerals. According to Pumpelly,† it replaces feldspar and various zeolites in the Lake Superior amygdaloids; and most of the large masses of copper there found are believed to be metasomatic.

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\* *U. S. Geol. Surv.*, Folio 38.

† *Geol. Surv. Mich.*, vol. i., part ii., p. 19, *et seq.*



*Gold and Silver.*—Native gold and silver are likewise important results of replacement in many veins. It is well known that masses of these metals are occasionally found in the country-rock away from the fissure; and these occurrences are probably to be interpreted as metasomatic, though the process has not been followed in its details.

Gold is also often contained in the replacing pyrite and other sulphides; and free gold can be obtained by panning from certain kinds of altered vein-rock. But caution should always be observed in stating such observations. I have known instances of supposed replacement where, in fact, all the value was derived from the filling of minute fissures and cracks.

#### *Resistant Minerals.*

Among the minerals which yield not at all or only with difficulty to metasomatic influences are apatite, muscovite, zircon and chromite. The resistance of apatite is very remarkable; for according to R. Müller\* apatite is soluble with comparative ease in water containing carbon-dioxide.

### PART III.

#### THE FISSURE-VEINS CLASSIFIED ACCORDING TO METASOMATIC PROCESSES.

Under this head, I suggest fourteen classes of fissure-veins, each usually characterized by its own distinctive metasomatic process. These fourteen divisions are not offered as a permanent classification, though most of them are sharply defined. The principle is not unqualifiedly good for a genetic classification, for the reason that the same waters may cause a different metasomatic development in different rocks.

The list, in each title of which the first word indicates the predominant metasomatic mineral or process, is as follows: 1. Topaz-cassiterite veins; 2. Skapolitic apatite veins; 3. Tourmalinic gold-copper veins; 4. Biotitic gold-copper veins; 5. Propylitic gold- and silver-veins; 6. Fluoritic gold-tellurium veins; 7. Sericitic and kaolinic gold- and silver-veins; 8. Sericitic and calcitic gold- and silver-veins; 9. Siliceic and calcitic quicksilver-veins; 10. Sericitic copper-silver veins; 11. Siliceic

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\* *Tsch. Min. Mitt.*, p. 25, 1877.



and dolomitic silver-lead veins; 12. Sideritic silver-lead veins; 13. Sericitic silver-lead veins; 14. Zeolitic copper- and silver-veins.

### 1. *Topaz-Cassiterite Veins.*

This sharply defined class is characterized by exceedingly strong metasomatic action, with fluorine as mineralizing agent, resulting in often coarse-grained, altered rocks, containing topaz and sometimes tourmaline, besides an often considerable percentage of cassiterite.

The cassiterite-veins are characterized by their occurrence in connection with intrusive igneous rocks, and by the pneumatolytic change of the country-rock to *greisen*, a granular rock consisting chiefly of quartz, topaz and white mica, usually containing fluor and lithia. Tourmaline and cassiterite are usually accessory constituents of this rock. The feldspar and the brown mica of the original rock are destroyed, and the minerals mentioned above are added. Topaz often forms pseudomorphs after quartz; cassiterite, tourmaline and topaz, after feldspar. The alteration of the country-rock varies somewhat in chemical aspects, but is distinguished by strongly marked transportation of substance.

In the granular greisen, the new minerals appear as individuals of considerable extent and optical continuity, perhaps indicating that the processes by which it was formed were more active and energetic than those producing the aggregate structure commonly found in altered vein-rocks. The minerals found in the metasomatic wall-rock appear also in the fissures themselves; hence the same chemical process must have been active in both. Other rocks, such as gneiss, quartz, porphyry and rhyolite, show similar alteration, though tin-deposits do not so commonly occur in them. A notable feature of the cassiterite-veins is the occurrence of apatite, a mineral generally unknown in fissure veins. Under ordinary circumstances, in altered vein-rocks, apatite is the last mineral to remain fresh, after all other primary minerals have been destroyed.

Vogt's explanation\* of the genesis of cassiterite-veins and the alteration of their wall-rocks follows closely the previously expressed views of Elie de Beaumont, Daubrée, Le Neve Fos-

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\* J. H. L. Vogt, *Zeitschr. f. prakt. Geologie*, 1895, p. 145.



ter and Dalmer. He assumes that they were formed immediately after, or even during, the granitic eruptions, and, further, that the mineral solutions originated by the action of hydrofluoric acid and hydrochloric acid on the magma, still entirely or partly in igneous fusion. By means of these, fluorides of silicon, tin, boron and lithium were extracted, as well as phosphoric acid. These solutions took place under pneumatolytic conditions, that is, the "critical point"\* had been passed and the substances were present in a gaseous state in spite of the high pressure. These extracts in gaseous state ascended on the previously formed fissures and strongly attacked the adjoining country-rock, changing it to greisen by means of replacement by minerals containing fluorine and other mineralizing agents. Different rocks were, perhaps, not affected exactly in the same way. For instance, the altered product resulting from schists is not quite similar to that resulting from granite, this being possibly due to the fact that the schists were not heated to such a degree as was the granite. While the formation of the greisen took place after the consolidation of the rock, as is evidenced by the fact that fissures could form in it, still it is believed that the temperature must have been very high, and, in fact, that the lower masses of the granite were not yet consolidated.

*Altenberg and Zinnwald, Saxony.*—The tin-deposits of Altenberg and Zinnwald, in Saxony, have been lately investigated by K. Dalmer.† The cassiterite-deposits of Altenberg consist, as is well known, of a number of ore-fissures which sometimes carry a notable amount of quartz, mica and topaz, as well as cassiterite. Over a considerable area traversed by these veinlets appears a greisen, locally called *zwitter*, which Mr. Dalmer shows to have resulted unquestionably from the metasomatic alteration of the granite. The process consisted of a replacement of feldspar, principally orthoclase, by topaz containing lithium and fluorine. The beginning of the process is often

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\* The critical temperature for water is  $+365^{\circ}$  C. at a pressure of 200 atmospheres. For most other substances the critical point is passed below this temperature and pressure. It is, perhaps, not needless to state that the passing of the critical temperature does not mean that the substances are dissociated.

† *Erläuterungen zur Geologischen Spezialkarte des Königreichs Sachsen, Section "Altenberg-Zinnwald,"* Leipzig, 1890.



visible, small strings of aggregates of mica and topaz pervading the feldspar. These strings repeatedly cross each other, and by extension of the mineral individuals complete replacement is attained. The greisen consists of: quartz, 50.28; topaz, 12.14; mica, 36.80; and cassiterite, 0.43; total, 99.65 per cent.

Dr. Dalmer has calculated the composition of the rock from these percentages, and obtained a result which closely agrees with the old analysis of the same rock by Rube, quoted in Cotta's *Gangstudien*. The following table shows the result, I being the fresh granite and II the altered product:

	I. Per Cent.	II. Per Cent.
SiO <sub>2</sub> , . . . . .	74.68	70.41
TiO <sub>2</sub> , . . . . .	0.71	0.49
SnO <sub>2</sub> , . . . . .	0.09	0.49*
Al <sub>2</sub> O <sub>3</sub> , . . . . .	12.73	14.86
Fe <sub>2</sub> O <sub>3</sub> , . . . . .	.....	1.42
FeO, . . . . .	3.00	5.09
CuO, . . . . .	0.50	.....
MnO, . . . . .	.....	0.29
CaO, . . . . .	0.09	0.21
MgO, . . . . .	0.35	0.09
K <sub>2</sub> O, . . . . .	4.64	3.01
Na <sub>2</sub> O + Li <sub>2</sub> O, . . . . .	1.54	0.98
Fl, . . . . .	.....	3.10
H <sub>2</sub> O, . . . . .	1.17	.....
	<hr/> 99.50	<hr/> 100.44

From these two analyses it is clear that the formation of greisen does not by any means involve silicification. Dalmer concludes that the principal changes consisted in the addition of FeO, Fl, SnO<sub>2</sub>, and possibly Al<sub>2</sub>O<sub>3</sub>, while K<sub>2</sub>O, Na<sub>2</sub>O and SiO<sub>2</sub> have been subtracted. In the absence of further knowledge of the relations of volume during the alteration, it is scarcely possible to conclude from the comparison of these analyses alone what the actual changes have been. The determination of specific gravities of the rocks would probably help to obtain a clearer insight in regard to this matter. This much is evident, that the mineral aggregate of the granite has changed to a new aggregate of greater density.

It will be observed that the second analysis contains no water. This has probably been unintentionally omitted, as it must

\* As cassiterite, 0.43; in mica, chemically combined, 0.06.



surely be present, being contained, chemically combined, both in topaz and in the lithium-mica.

In view of the fact that in this alteration not only the potassium-aluminum silicate, muscovite, but also the pure aluminum fluo-silicate or topaz appears, it is interesting to note that metasomatic kaolin is undoubtedly present in cassiterite-veins. Pseudomorphs of it after topaz have been frequently observed, and it is often stated that "steinmark" is present in the veins; this being really only a synonym for kaolin. Daubrée long ago called attention to the connection of kaolin with cassiterite-veins.

In several places the alteration of the granite and the adjoining porphyry is of a radically different character, and consists in a complete silicification. While this is not the normal process, yet it appears fairly common, and must be taken into consideration in attempting to explain the genesis of these veins.

*Mt. Bischoff, Tasmania*: The rocks of the tin-deposits of Mt. Bischoff, in Tasmania, have lately been described by W. von Fireks,\* who devotes considerable space to the alteration which they have suffered. The tin-deposits appear in an area of quartzites and clay-slates with dikes of quartz-porphyry. Granite is present some distance from the mines. The deposits are in part fissure-veins carrying cassiterite, pyrite, arsenopyrite, fluorite, wolframite, tourmaline and siderite. The latter mineral is notable, because not usually present in veins of this character. Another part of the deposits is formed by replacement, chiefly of porphyry dikes. All rocks in the vicinity of the mines are much altered. The schists and slates contain much tourmaline, and are in part changed to typical tourmalin-fels by complete replacement, only a few grains of the original rock remaining. Besides the tourmaline, some siderite also appears, while topaz is present in but small quantity. These altered schists contain cassiterite (rare), and also pyrite, arsenopyrite, pyrrhotite, fluorite, calcite, siderite and pyrophyllite as metasomatic products. The tourmalinization begins with the appearance of needles and bunches of crystals of tourmaline traversing fresh quartz grains, as shown in Fig. 23. These tourmaline crystals, by further growth, finally replace the

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\* *Zeitschr. d. d. geol. Ges.*, Bd. li., p. 433, 1899.



quartz altogether. According to the description, the fissure-veins must have been produced partly, at least, by processes of filling. Where they traverse the schists, their walls show impregnation of ores and the development of a great quantity of sericite. Sometimes, it should be added, the wall-rocks are completely silicified. Of greatest interest are the quartz-porphry dikes and their alteration-products. The principal secondary mineral in these dikes is topaz, while tourmaline is only of secondary importance. The groundmass of the porphyry is changed to aggregates of topaz and quartz. The quartz phenocrysts are usually intact, while the feldspars are often completely replaced with cassiterite, pyrite, pyrrhotite, arsenopyrite and fluorite, as shown in Fig. 22. In the final product, the feldspar and mica have disappeared completely, the zircon being, besides quartz, the only mineral which has withstood the metasomatic influences. Here again siderite appears occasionally, seemingly of simultaneous formation with the other metasomatic constituents. There is, as shown by the author, a great similarity between the metasomatic action in these deposits and that described from the vicinity of Schneckenstein, in Saxony, by Mr. M. Schroeder.\*

None of the rocks from Tasmania can well be designated as "greisen"—a name which ought to be reserved for the granular alteration-products of granite consisting of quartz, lithion-mica, topaz and cassiterite. Here again, as at Altenberg, we find occasionally, seemingly as an exception, a change in the metasomatic processes resulting in complete silicification of the wall-rock.

Prof. R. Beck† has discussed the tin-ore deposits from Banca and Billiton, in referring to the work of Mr. Verbeek on the same subject. It has been shown by Prof. Cl. Winkler that many granites and rocks allied to *hornfels* contain a small amount (from 0.01 to 0.07 per cent.) of oxide of tin. This is not cassiterite, but appears to be chemically combined with silicates, partially replacing  $\text{SiO}_2$ . Sandberger had, indeed, also shown long ago the presence of tin in certain muscovites from different places in Europe. Another very interesting fact shown by Mr.

\* *Erläut. z. Geol. Sp. Karte des Königr., Sachsen, Leipzig, 1885, Section "Schneckenstein."*

† *Zeitschn. prakt. Geologie, 1898, p. 121.*



Verbeek is a stanniferous siliceous sinter, deposited at a hot spring in Malacca. This sinter contains, according to an analysis by St. Meunier,  $\text{SiO}_2$ , 91.8;  $\text{SnO}_2$ , 0.5;  $\text{Fe}_2\text{O}_3$ , 0.2, and  $\text{H}_2\text{O}$ , 7.5 per cent.

This observation possesses the greatest importance for our knowledge of tin-deposits, as it shows that the metal may be held in solution and deposited at ordinary pressure by thermal waters. Prof. Beck shows the presence of primary cassiterite in some granites from the same locality, and also points out that the veins are practically identical with tin-deposits from other parts of the world, being characterized by an often strong alteration of the adjoining country-rock, converting it into typical greisen. The feldspar is replaced by topaz, cassiterite and muscovite. The typical greisen is illustrated in Fig. 24, copied from Prof. Beck's article.

## 2. Scapolite-Apatite Veins.

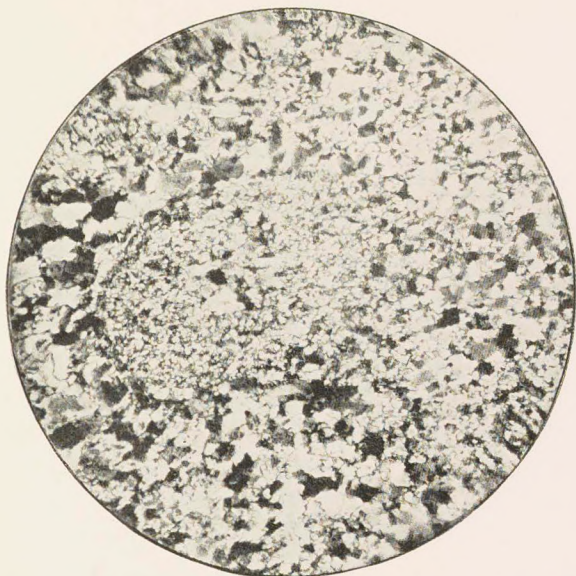
This interesting group of veins has lately been described in detail by Prof. Vogt.\* It is characterized by some most remarkable features, closely relating it on one hand to the group of the cassiterite-veins, but showing, on the other hand, strong relationships with the pegmatite-veins, formed under pneumatolytic conditions and exceedingly high temperature and pressure. The structural features of scapolite-apatite veins are not those of fissure-veins, as they chiefly follow contraction-joints (in gabbro). Indeed, this may be said to some extent of cassiterite-veins; but the latter often also follow strong, well-defined fissures. At any rate, it seems probable that the apatite-veins were formed almost simultaneously with, or very closely following, the solidification of the magma.

The characteristic minerals are apatite, phosphates, rutile, pyrrhotite, specularite, enstatite, scapolite, hornblende and malacolite, many of which are absolutely foreign to ordinary fissure-veins. A most characteristic feature is the presence of chlorine (in apatite and scapolite), just as fluorine persistently appears in cassiterite-veins. In the gabbro adjoining the vein-filling, the labradorite is usually altered to scapolite, and the diallage to hornblende. This alteration is explained (*loc. cit.*, p. 456) as a saturation of the country-rock under high pressure

\* J. H. L. Vogt, *Zeitschr. f. prakt. Geol.*, 1895, p. 367.



FIG. 1.



Silicified Calcareous Shale with Outline of Foraminiferal Test. Diadem lode, Plumas county, Cal. (After H. W. Turner.) Crossed nicols. All quartz. Magnified 29 diameters.

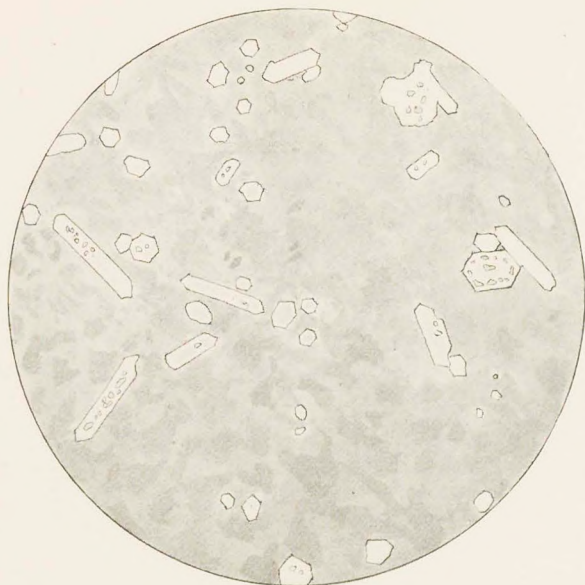
FIG. 2.



Primary Vein Quartz from Filling. Federal Loan mine, Nevada county, Cal. Crossed nicols. All Quartz. Magnified 14 diameters.

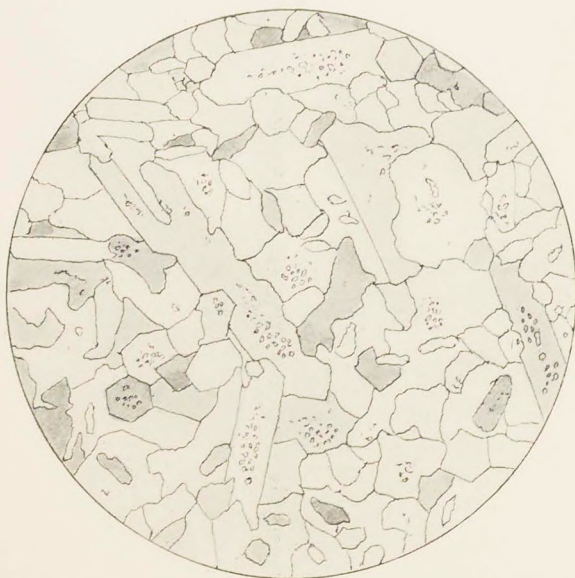


FIG. 3.



Incipient Silicification of Limestone. Aspen, Colo. White areas represent quartz crystals with small inclusions of limestone. Magnified 30 diameters.

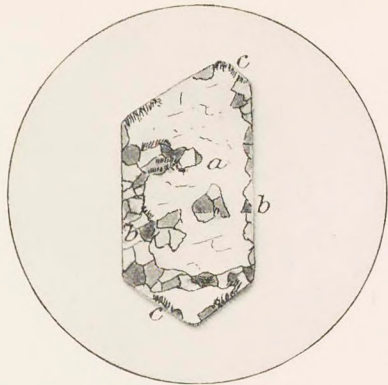
FIG. 4.



Silicified Limestone ("Jasperoid"). Aspen, Colo. Crossed nicols. All quartz. Small inclusions of calcite in some of the grains. Magnified 30 diameters.



FIG. 5.



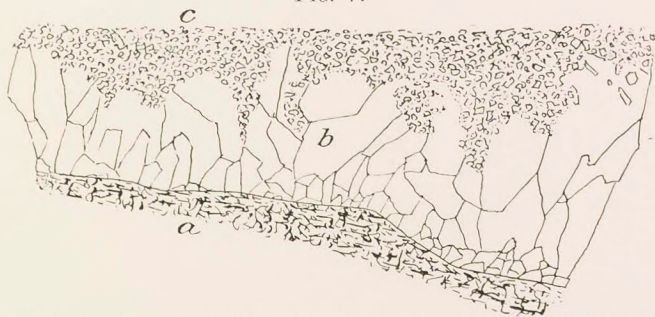
Incipient Silicification of Orthoclase Crystal in Rhyolite. Silver City, Idaho. Crossed nicols. *a*, Orthoclase; *b*, secondary quartz; *c*, sericite. Magnified 34 diameters.

FIG. 6.



Hornblende Crystal with Partial Chloritization and Silicification; in Propylitic Andesite. Virginia City, Nevada. (After G. F. Becker.) White, quartz and calcite; grey, chlorite; dark grey, hornblende. Magnified 70 diameters.

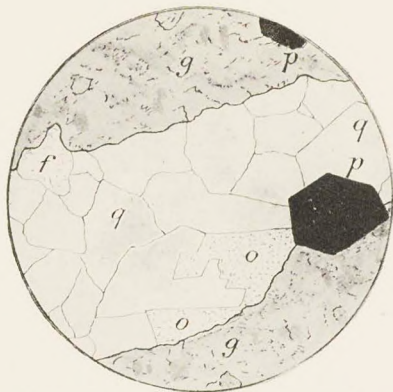
FIG. 7.



Veinlet of Quartz (*b*) on Chloritized Basalt (*a*), Replacing Silicified Rhyolite (*c*). Bishop vein, Silver City, Idaho. Magnified 11 diameters.



FIG. 8.



Filled Veinlet in Andesite Breccia. Independence mine, Cripple Creek, Colo. *q*, Quartz; *o*, valencianite (orthoclase); *p*, pyrite; *f*, fluorite; *g*, ground-mass of breccia. Fluorite and pyrite partly replacing ground-mass. Magnified 11 diameters.

FIG. 9.



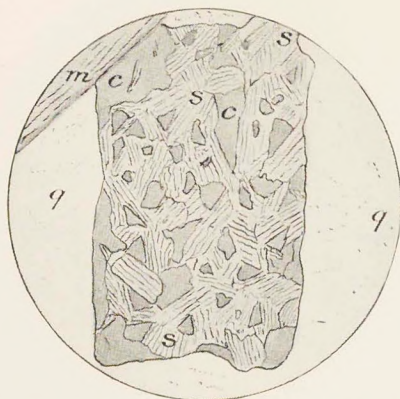
Fluorite Ore, Replacing Phonolite. Portland mine, Cripple Creek, Colo. *p*, Pyrite; *q*, quartz, coarser and finer grains; *f*, fluorite. Magnified 50 diameters.







FIG. 12.



Andesine Crystal in Granodiorite, Replaced by Sericite and Calcite. Pinetree vein, Ophir, Placer county, Cal. *q*, Quartz; *m*, muscovite; *c*, calcite; *s*, sericite. Magnified 80 diameters.

FIG. 13.



Quartz Grain in Same Section, Partly Replaced by Calcite. *q*, Quartz; *c*, calcite with some sericite replacing from outside; *c*, secondary calcite grains forming on inclined fissure-plane in quartz. Magnified 80 diameters.

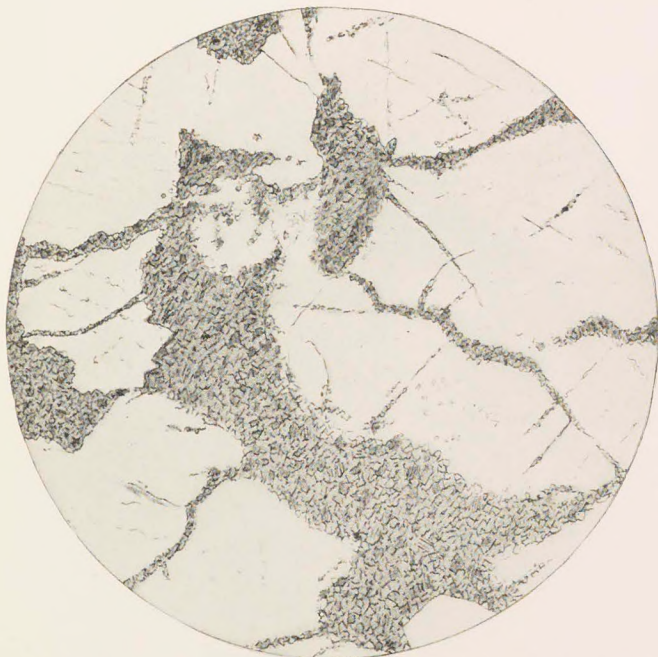


FIG. 14.



Fluorite Replacing Limestone. Florence mine, Judith Mountains, Mont. *f*, Fluorite; *l*, limestone; *q*, secondary quartz. Magnified 7 diameters.

FIG. 15.



Metasomatic Replacement of Quartz in Granodiorite by Calcite and Sericite. Providence mine, Nevada City, Cal. White areas quartz. Shaded areas fine-grained calcite with some sericite. Magnified 52 diameters.



FIG. 16.



Siderite with Pyrite and Galena, Replacing Quartzite. Helena and Frisco mine, Coeur d'Alene, Idaho. *q*, Quartz grains; *s*, sericite; *si*, siderite; black, galena and pyrite. Magnified 100 diameters.

FIG. 17.



Replaced Quartzite, Same Locality as Fig. 16. Black, galena; *z*, zinc-blende; *q*, quartz; *s*, sericite; *si*, granular siderite. Quartzite in same section gradually changing to this ore. Magnified 35 diameters.

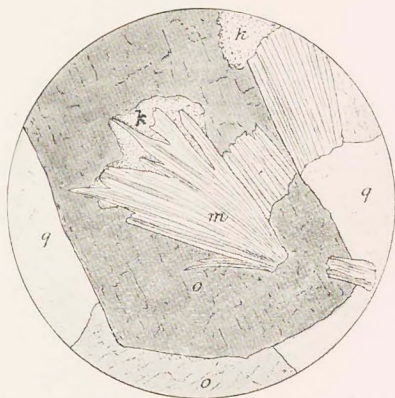


FIG. 18.



Quartzite Partly Replaced by Siderite and Pyrite. Helena and Frisco mine, Cœur d'Alene, Idaho. *q*, Quartz grains; *s*, sericite; *sl*, siderite with partly rhombohedral form; black, pyrite. Magnified 100 diameters.

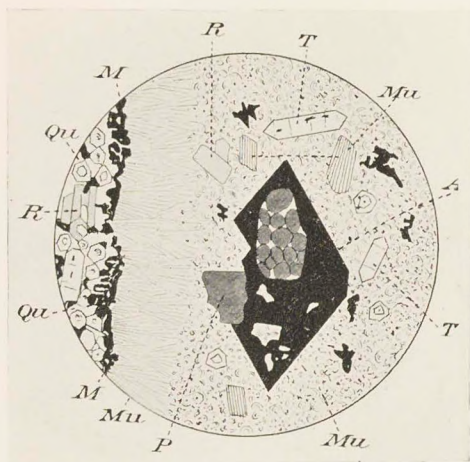
FIG. 19.



Orthoclase Partially Replaced by Muscovite and Kaolinite. From quartz-monzonite adjoining recent vein, Boulder, Mont. *o*, Orthoclase; *q*, quartz; *m*, muscovite; *k*, kaolinite. Magnified 22 diameters.



FIG. 20.



Part of Andalusite Crystal Altered into Muscovite, Arsenopyrite, etc. Passagem gold-quartz vein, Brazil. (After E. Hussak.) *M*, Pyrrhotite; *A*, arsenopyrite; *P*, pyrite; *Qu*, quartz; *R*, rutile; *Mu*, muscovite; *T*, tourmaline.

FIG. 21.



Replacement-Veinlet of Tourmaline in Fresh Andesine Grain. Keystone mine, Meadow Lake, Nevada county, Cal. *t*, Tourmaline; *f*, andesine; *e*, epidote; *s*, sericite. Magnified 50 diameters.



FIG. 22.



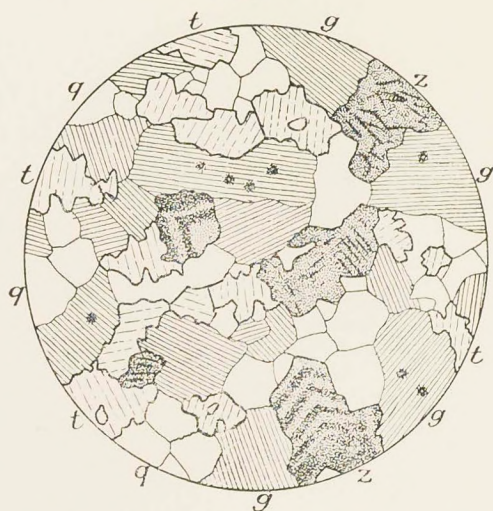
Feldspar Crystal Replaced by Topaz, Quartz, Fluorite and Cassiterite, in Ground-Mass Converted to Partly Radial Aggregates of Topaz. Mount Bischoff, Tasmania. (After W. von Fireks.)

FIG. 23.



Incipient Tourmalinization of Quartzite. Three quartz grains shown. Needles single and in bunches, of tourmaline. Mount Bischoff, Tasmania. (After W. von Fireks.)

FIG. 24.



"Greisen" from Tin-Deposits of Bangka, Malay Peninsula. Derived from granite. (After R. Beck.) *g*, Lithion-mica; *q*, quartz; *z*, cassiterite; *t*, topaz. Stippled spots in mica consist of zircons and rutiles, surrounded by polychroic ring. Slightly magnified.

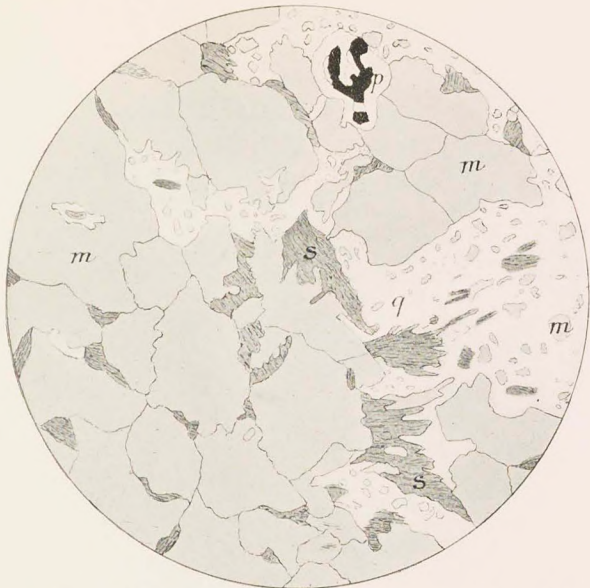
FIG. 25.



Altered Quartz-Mica-Diorite. Croesus mine, Wood River, Idaho. *a*, Galena; *b*, arsenopyrite; *c*, chalcopyrite; *d*, sericite; *e*, quartz with secondary fluid inclusions; *f*, rutile; *g*, chlorite. Magnified  $19\frac{1}{2}$  diameters.



FIG. 26.



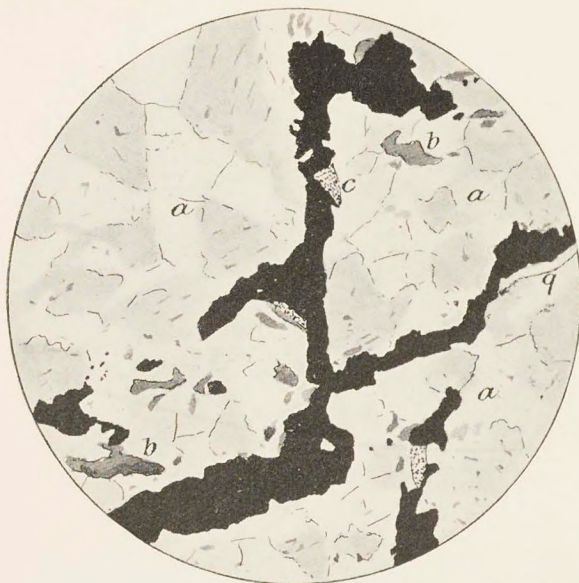
Altered Serpentine. Idaho mine, Grass Valley, Cal. *m*, Magnesite; *s*, serpentine; *p*, pyrite; *q*, fine granular quartz. Magnified 15 diameters.

FIG. 27.



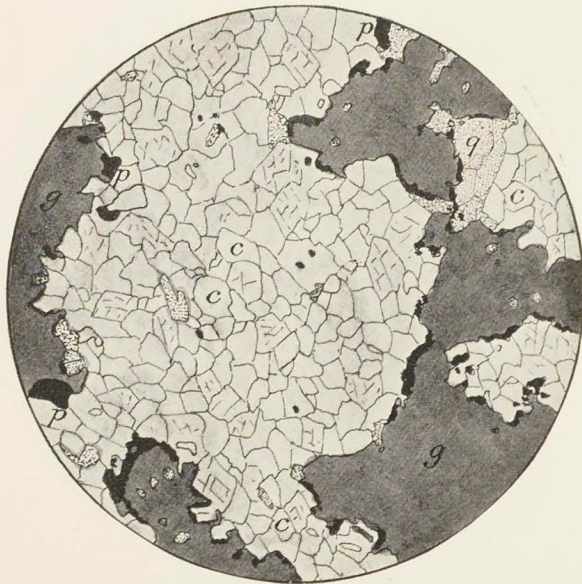
Altered Granodiorite. Bellefontaine mine, Nevada City, Cal. *m*, Fine aggregate of sericite, with a little calcite and secondary quartz, replacing orthoclase and andesine; *b*, original biotite altered to sericite; *q*, original quartz; black, pyrite with included sericite. Magnified 15 diameters.

FIG. 28.



Replacement-Vein in Syenite Rock. War Eagle mine, Rossland, British Columbia. *a*, Granular aggregate of orthoclase with very little sericite; black, secondary pyrrhotite; *b*, secondary biotite; *q*, secondary quartz; *c*, chlorite. Magnified 60 diameters.

FIG. 29.



Galena, Replacing Crystalline Limestone. Elkhorn mine, Montana. *g*, Galena; *p*, pyrite; *c*, calcite grains of limestone; *q*, secondary quartz. Magnified 15 diameters.



FIG. 30.



Quartzite Showing Filled Quartz Veinlet and Accompanying Galena, Replacing the Quartzite on One Side of the Filled Fissure. The quartzite contains some replacing siderite. Bunker Hill and Sullivan mine, Cœur d'Alene, Idaho. Black, galena; white, quartz; grey, quartzite. Natural size.

by the sodium chloride which acted as a mineralizing agent during the formation of the veins.

### 3. *Tourmalinic Gold-Copper Veins.*

In the type of veins distinguished by a gangue of tourmaline and quartz the country-rock is generally subject to strong metasomatic changes. The vein-forming agents, which contained boron and some fluorine, appear to have attacked the adjoining rock strongly, and caused a more or less complete metasomatic conversion into tourmaline. Groddeck\* has described an occurrence of this kind from Tamaya, Chili, in which veins containing copper-ores cut gabbro and porphyrites. The tourmaline is here not only present in the filling of the fissure but is also distributed through the adjoining country-rock. A further contribution to the knowledge of veins carrying tourmaline was given by A. W. Stelzner† in his description of occurrences of this kind from Chili. The rocks examined, from the mining district of Las Condes, 90 miles east of St. Iago, consist of granite and greenish porphyritic rocks, which the author is inclined to consider as altered andesites. The vein-filling was pyrite, chalcopyrite, quartz and a loose porous mass of tourmaline needles. By a specific-gravity separation of the latter, Stelzner obtained, as a residue, zircon in well-developed crystals, as well as specularite and anatase. The zircon is probably developed under the influence of the vein-forming solutions, the anatase and specularite quite certainly so. Again the fact is emphasized that the adjoining country-rock is bleached and filled with pyrite and tourmaline.

Dr. E. Hussak‡ has recently described the auriferous quartz-vein of Passagem, in Minas Geraes, Brazil. This vein, which lies, parallel to the stratification, between mica schist and itabirite (hematite-mica-schist), shows a filling of quartz, tourmaline, and arsenopyrite, with smaller quantities of pyrite and pyrrhotite. The arsenopyrite is strongly auriferous. A very interesting feature is the occurrence of zircon and monazite in the ore, formed apparently simultaneously with it. Here, too, the tourmaline is present in the adjoining country-rock. Musco-

\* *Zeitschr. d. d. Geol. Ges.*, 39, 1889, p. 237.

† *Zeitschr. f. prakt. Geologie*, 1887, p. 41.

‡ *Zeitschr. f. prakt. Geologie*, 1898, p. 345.



vite or sericite is also described as very plentiful in the schistose rock adjoining the vein. Certain crystals of andalusite, occurring (as inclusions?) in the vein, are completely altered into sericite, rutile, arsenopyrite and pyrite, as is well shown in Fig. 20 (reproduced from Dr. Hussak's paper). The author concludes from his study that the deposit is a product of igneous injection, and should be considered a dike rather than a fissure-vein, basing this conclusion largely on the occurrence of zircon, monazite, tourmaline and staurolite in the adjoining rock. It is a question whether this argument will carry conviction. From Dr. Hussak's excellent descriptions I should be inclined to consider this interesting occurrence as a fissure-vein deposited by aqueous agencies, though, perhaps, at a higher temperature than ordinary veins. The contact-minerals cited by the author do not appear to be confined to the adjoining rock, but are present in the whole series of schists. The very schistose and sericitic quartzite forming the wall of the vein, and the presence of pseudomorphic sericite after andalusite, as well as the apparently simultaneous forming of arsenopyrite and sericite, appear to me evidence that the deposit of Passagem is really a normal vein. The tourmaline is here also present in the country-rock, apparently replacing it to a greater or lesser degree.

Again, similar deposits have been described from Meadow Lake, Nevada county, Cal.,\* where granitic and dioritic rocks contain fissure-veins with pyrite, arsenopyrite, pyrrhotite, zincblende, and various secondary copper-ores, indicating primary chalcopyrite in a gangue of quartz and tourmaline, with which some yellow epidote is usually associated. Chlorite is also common in the gangue as well as a brown mica, probably biotite. A colorless mica and a little calcite were also observed. In contrast to the usually clearly defined fissure-veins of the gold-belt of California, in which the quartz-filling is the predominant ore, these veins show very irregular and undefined walls, and it is clear that the mineral-forming solutions rose along very narrow fissures, from which they penetrated more or less deeply into the adjoining country-rock, and there, by metasomatic replacement deposited the auriferous ores. One of these occurrences

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\* Waldemar Lindgren, *Am. Jour. of Sci.*, vol. xlv., September, 1893.



is illustrated in Fig. 21. The specimen is from the Keystone mine, and shows a granitic rock traversed by a narrow fissure, from which an intense alteration has proceeded, converting the immediate rock into an aggregate of quartz and tourmaline. The metasomatic process is well shown in the figure.

Prof. Vogt describes\* certain veins in Telemarken, Norway, which he considers as related to the cassiterite-veins proper. These contain chalcopyrite, bornite, and chalcocite, also a little native silver and gold, all associated with a gangue of fluorite, tourmaline, apatite, muscovite and calcite. They are considered to be genetically connected with the granite in which they appear, and the presence of tourmaline and apatite certainly suggests their close relationship to normal cassiterite-veins. The country-rock is a normal biotite-granite, with orthoclase, microcline and oligoclase, and no muscovite. The alteration extends for several feet on both sides of the veins, and all transitions are plainly visible. The first part of the process consists in a peripheric change of biotite to muscovite and a little epidote; then the feldspars are attacked, muscovite and quartz together with a little calcite forming on the cleavage-planes; and finally the feldspars and biotite are entirely decomposed. The result is muscovite, quartz, calcite, rutile, zircon and apatite,—the latter two not altered, but constituting the only material remaining fresh from the unaltered rock. A little fluorite, chalcopyrite or bornite is also occasionally present in the product of alteration. Regarded from a chemical standpoint the process is not always the same. Sometimes, according to Vogt, substance is added; sometimes taken away. Quartz may occasionally prevail; at other places muscovite predominates. Prof. Vogt calls this altered rock a greisen; but the process of alteration as described by him is so nearly that of ordinary sericitic replacement that it may be questionable whether it would not be better to reserve the term greisen for the characteristic rock accompanying the cassiterite-veins. The process of formation in the case of the Telemarken veins was probably not carried on under the extreme conditions attending the normal cassiterite-veins.

The three classes of veins described above are undoubtedly

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\* *Zeitschr. f. prakt. Geol.*, 1895, p. 147.



closely related and form a group, which, however, is connected by transitions from the following classes. In their whole development a distinct genetic connection with intrusive rocks is recognizable, and they seem to have been formed under exceptionally high pressure and temperature—in fact, partly under pneumatolytic conditions. The metasomatic action on the country-rock is very strong, and the presence of fluorine, chlorine or boron is characteristic. It is well to emphasize, however, that fluorine and boron appear in many other veins which certainly have not originated under pneumatolytic conditions, or even under high temperature or pressure. The three foregoing classes appear to form a transition from pegmatite-veins to ordinary-fissure veins.

#### 4. *Biotitic Gold-Copper Veins.*

This class, of which few representatives are thus far known, are exemplified in the veins of Rossland, British Columbia. They are well-marked fissure-veins, contained in granular, intrusive rocks of great variety, ranging from diorites to monzonites and even syenites. The ore-minerals are pyrrhotite, chalcopyrite and a little arsenopyrite, all containing gold, but usually not in a free state, amenable to amalgamation; the principal gangue-mineral is biotite, with a little quartz, calcite, muscovite, amphibole, chlorite, tourmaline and garnet.

The veins are excellent examples of replacement-deposits, as there is but little material which can be identified as the filling of open cavities, while most of the ore has been formed by replacement of the rock-forming minerals on both sides of narrow fissures. The original hornblende of the rock is altered to aggregates of biotite foils, which also invade the feldspars; and simultaneously the feldspar substance is replaced from small cracks by pyrrhotite and chalcopyrite, forming a characteristic network which, by gradual extension, finally replaces the whole rock. One of these replacement-veinlets is illustrated in Fig. 28. The sulphides do not as a whole have crystalline outlines, though in some places the grains show crystal-faces. The secondary character of the sulphides is further shown by narrow linings of quartz, chlorite or biotite. The feldspar substance, generally clouded by interpositions of biotite, muscovite, etc., usually presents a narrow, clear rim adjoining the sulphides. Exten-



sive biotitization results in fine-grained siliceous rocks, consisting of brown mica and quartz, possibly also secondary feldspars. Green secondary amphibole was noted in places, embedded in calcite. The whole process is more characteristic of dynamic metamorphism than of ordinary fissure-veins, and it is probable that the veins were formed under actual unrelaxing compression. Strongly reducing conditions are indicated (otherwise pyrrhotite would not form so exclusively), and the absence of notable quantities of carbon-dioxide. Along secondary slips, below the water-level, the pyrrhotite may be transformed to pyrite. Epidote appears to be absent. The veins are earlier than an extensive system of lamprophyric dikes which cut across them. These dikes were no doubt closely connected with the principal intrusion of igneous rock; and the conclusion may be drawn that the mineralization followed pretty closely upon the consolidation of the rock.

#### 5. *Propylitic Gold- and Silver-Veins.*

*General Features.*—As the cassiterite-veins are closely connected genetically with certain intrusive rocks, so another group of veins shows a dependence on tertiary effusive rocks, such as andesites, dacites and basalts, in part also rhyolites and trachytes. In the vicinity of these veins there is a very extensive metasomatic action resulting in so-called propylite (named by Richthofen) which was regarded formerly as a primary rock-type, just as greisen has sometimes been regarded as a primary rock forming a variety of granite. But all fissure-veins in tertiary effusive rocks do not belong to this class; a considerable number belong under the head of sericitic veins. Rosenbusch expresses the process in the following apt words:\*

“The characteristic features of the propylitic *facies* consists in the loss of the glassy habit of the feldspars; in the chloritic alteration of the hornblende, biotite and pyroxene (often with an intermediate stage of uraltite), with simultaneous development of epidote; further, in alteration of the normal ground-mass into holocrystalline granular aggregates of feldspar, quartz, chlorite, epidote and calcite, and in a considerable development of sulphides” [usually pyrite].†

\* *Elemente der Gesteinslehre*, Stuttgart, 1898, p. 303.

† Rosenbusch adds (*loc. cit.* and *Mikr. Phys. d. Mass. Gest.*, Stuttgart, 1896, p. 91) that similar rocks (excepting the pyrite) may result from atmospheric weathering. Against this statement I would protest, referring to p. of this paper.



Chemically, the change is not considerable; the principal additions consist of water and sulphur; some substance is often subtracted, usually lime or magnesia, while the alkalies show slight change. The following analysis, taken from Mr. Clarence King's monograph on the Comstock Lode, shows the composition of a propylitic andesite:

	Per cent.
SiO <sub>2</sub> . . . . .	64.62
Al <sub>2</sub> O <sub>3</sub> . . . . .	11.70
FeO . . . . .	8.39
MgO . . . . .	1.18
CaO . . . . .	8.96
Na <sub>2</sub> O . . . . .	3.13
K <sub>2</sub> O . . . . .	1.95
H <sub>2</sub> O . . . . .	1.02
	<hr/> 100.95

Propylitic rocks occur in the vicinity of large fissure-veins and vein-systems in Tertiary effusive rocks—for instance, at the Comstock, Nevada; Pachuca and Real del Monte, Mexico; in the South American Andes; and in Hungary and Transylvania. Although the propylite indicates the general metasomatic process in these veins, it is not uncommon to find rocks and soft clays containing sericite as a product of the extreme metasomatic action very close to the vein. The waters principally active during the formation of the propylitic veins probably contained only a small amount of carbon dioxide and very little lime, but may have been rich in sulphuretted hydrogen.

The filling of open spaces is a very important process in these veins, as may be expected from their formation comparatively near the surface; and this filling usually constitutes the principal ore, though altered rock, containing enough gold and silver to be classed as ore, occurs extensively in many places.

The primary character of propylite as a separate eruption is to some extent still upheld by Zirkel,\* but his arguments are not convincing.

*The Comstock Lode.*—The relations at the Comstock lode, described by G. F. Becker,† are exceedingly interesting, because the deposit, besides being celebrated for its immense

\* *Lehrbuch der Petrographie*, ii., p. 485.

† G. F. Becker, "Geology of the Comstock Lode," *Monograph III., U. S. Geol. Surv.*



production, is a representative type. The vein, which carries both silver and gold, is surrounded by an area of extreme alteration, occupying a space of about 5 by 2 miles, affecting alike the diorite, diabase and andesite.\* In the course of this alteration the hornblende and augite are changed to chlorite, which also infiltrates the feldspars. Pyrite is present in the rock in proportion to its alteration, and is probably developed from the ferro-magnesian silicates; to a lesser degree, from the magnetite. The feldspars are decidedly less easily altered than the silicates mentioned. Beginning alteration is made apparent by specks of calcite. Later on, quartz grains and an opaque white, doubtful substance appears. No kaolinite was recognized, and if present, it occurs in very subordinate quantities only. Epidote is more abundant near the surface than in depth, and appears to result from the further alteration of chlorite, under the influence of calcic solutions derived from the feldspars. Muscovite as a product of alteration of the feldspars is absent.

The extreme alteration is represented by the so-called clays, which were formerly supposed to consist largely of kaolin. Becker shows this assumption to be erroneous, and gives analyses to show that the clays are simply derived from the normal rocks by a partial alteration. An examination of the analyses quoted from the monograph of Clarence King, in Table I., following page 152 of Becker's monograph, will show that in the diorites, andesites and diabases the  $\text{Na}_2\text{O}$  decidedly exceeds the  $\text{K}_2\text{O}$ . In two of the three analyses of "propylites," which are simply rocks subjected to incipient thermal alteration, the  $\text{K}_2\text{O}$  is present in decidedly larger quantity than the  $\text{Na}_2\text{O}$ . In the remaining "propylite" analysis, the reverse is true. The four analyses of the "clays," or the extremely altered, crushed and bleached material adjoining the veins, run as shown in table on page 71.

The quantitative relations of the alkalis clearly show a concentration of potash and a leaching of soda. There can scarcely be any doubt that these clays really consist of 30 to 40 per cent. of finely divided sericite, mixed with some quartz and residual rock.

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\* Without wishing to reopen the Comstock question, I would state my strong belief that these three rocks are separate and independent eruptive bodies.



*Analyses of Comstock Clays.*

	I.	II.	III.	IV.
	Per cent.	Per cent.	Per cent.	Per cent.
SiO <sub>2</sub> .....	60.02	59.71	65.69	39.52
TiO <sub>2</sub> .....	.....	.....	.....	.....
Al <sub>2</sub> O <sub>3</sub> .....	12.15	17.59	15.39	15.97
Fe <sub>2</sub> O <sub>3</sub> .....	4.38	5.04	2.11	4.47
FeO.....	.....	.....	.....	.....
MnO.....	.....	.....	.....	.....
CaO.....	6.00	0.73	1.66	9.20
MgO.....	1.40	4.41	2.85	3.40
Na <sub>2</sub> O.....	0.45	1.01	2.36	.....
K <sub>2</sub> O.....	1.23	3.98	4.64	3.11
CO <sub>2</sub> .....	3.17	.....	.....	6.20
FeS <sub>2</sub> .....	1.84	3.58	2.84	9.18
P <sub>2</sub> O <sub>5</sub> .....	0.34	trace	trace	trace
H <sub>2</sub> O.....	8.09	4.19*	2.80*	9.95
Total.....	99.07	100.24	100.34	101.00

## Locality.

I. Yellow Jacket east clay, . . . . .	S. W. Johnson.
II. Chollar west clay, . . . . .	W. G. Mixer.
III. Hale and Norcross east clay, . . . . .	W. G. Mixer.
IV. Savage second station, . . . . .	S. W. Johnson.

## Analyst.

*The Veins of Nagyág, Hungary.*—In 1885, Béla von Inkey published an interesting report on the ore-deposits at Nagyág.† These consist, in brief, of a complicated system of not very persistent veins, cutting an eruptive mass of trachytic rocks breaking through Tertiary sediments, which in turn rest on older argillites. The deposits are famous as containing gold accompanied by various interesting tellurides. The whole occurrence bears in its geological relation some similarity to the deposits at Cripple Creek, Colo. The principal gangue is quartz, accompanied by galena, zinc-blende, pyrite, chalcopyrite, etc., besides gold and rich tellurides. In addition to the quartz, various carbonates are present. The fissures are small, but contain the (generally rich) ore as the filling of open spaces. The sedimentary rocks do not in general contain much valuable ore, although such occurrences are known. The ore-shoots are chiefly confined to the eruptive mass of trachyte. In the vicinity of the mineral deposits the trachytes are quite generally changed to so-called propylitic rocks, the change

\* By ignition.

† *Nagyág und seine Erzlagerstätten*, by Béla von Inkey, Budapest, 1885.



consisting in the development of chlorite in the ferro-magnesian minerals. It is, in fact, difficult to obtain fresh rocks anywhere in the vicinity. In the immediate vicinity of the veins, and in the whole zone in which the veins are closely massed, the rock has suffered another alteration, which Inkey refers to as a kaolinization, in consequence of which the rock loses its normal hardness and greyish or greenish color, and is transformed into a soft brownish yellow to white mass, resembling kaolin. The last traces of hornblende and augite are lost, and only carbonates replace them. The biotite is transformed to a soft talcose substance. The magnetite is often replaced by pyrite. Only the quartz remains unaltered, and, in connection with the pseudomorphs of biotite, affords the best criterion for recognizing the trachytic nature of this highly altered rock. This modification is so clearly connected with the veins that its origin from the fissures cannot be doubted. Where the rock is not altered, rich shoots are rarely found. Inkey thinks that this alteration clearly indicates, not superficial waters, but thermal waters ascending on the fissures. Both kinds of alteration, the chloritic as well as the "kaolinitic," are regarded as closely related to the genesis of the veins. The chloritic modification is supposed to have resulted from a sort of hydrometamorphic action preceding the immediate formation of the veins. This so-called kaolinized rock has been examined in more detail by Dr. Kollbeck,\* who showed it consists partly of sericite. Dr. Kollbeck separated the rock by means of heavy solutions, finding that, besides the sericite, it contained some pyrite (with a little arsenic, gold and silver), zircon and anatase, as well as a little apatite. The chief constituent fell between specific gravity 2.918 and 2.649, though most of it came down at 2.788. The analysis of the micaceous mineral gave the following composition:  $\text{SiO}_2$ , 48.67;  $\text{Al}_2\text{O}_3$ , 39.30;  $\text{Fe}_2\text{O}_3$ , 0.30;  $\text{MnO}$ , 0.25;  $\text{CaO}$ , 0.38;  $\text{MgO}$ , 1.42;  $\text{K}_2\text{O}$ , 3.73;  $\text{Na}_2\text{O}$ , 0.13;  $\text{H}_2\text{O}$ , 5.83;  $\text{CO}_2$ , 0.23;  $\text{FeS}_2$ , 0.43; total, 100.67 per cent.

As may be inferred from the variability of the specific gravity, the mineral is clearly not pure muscovite, but probably a mixture of sericite and kaolinite, as is shown by the high

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\* *Oesterr. Zeitschr. f. B. & H.-Wesen*, 1888, pp. 25-27.



percentage of alumina and water and the low percentage of potassa.

*Pachuca, Mexico.*—Another type of this class of veins is described by Messrs. J. Aguilera and E. Ordoñez.\* The well-known and very productive veins of Pachuca cut a series of Tertiary effusive rocks, principal among which is a pyroxene-andesite. Rhyolite and basalt are also present, but contain, near Pachuca, no mineral veins. The deposits are typical fissure-veins, filled with a gangue of quartz carrying in fine dissemination argentite, pyrite, galena, zinc-blende, stephanite and polybasite. The value is almost exclusively in silver, very little gold occurring. There is no ruby-silver; and in depth the veins are said to be impoverished by the appearance of large quantities of barren zinc-blende. The pyrite and galena contain a little silver, but no gold. Calcite appears in subordinate and varying quantities, as the latest gangue, filling interstices between quartz crusts. Inclusions of country-rock in sharp fragments are common in the quartz. On the whole, there can be no doubt that the ore in these veins is chiefly the filling of open cavities by quartz, as in the gold-quartz veins of California.

Over a large area in the vicinity of the veins the rocks contain much chlorite and quartz, with a little calcite. Close to the veins, the alteration is most intense. The country-rock is filled with small, perfect crystals of pyrite, which is always practically barren. Its sharply developed crystal-form contrasts with the generally anhedral form of the pyrite in the vein. Black sulphides occasionally, but rarely, appear in the country-rock next to the veins. These are, of course, rich. The rocks immediately adjoining the veins contain, besides pyrite, much chlorite, also some calcite and a considerable amount of secondary quartz. The latter is so abundant that the chief alteration near the vein is often a silicification, the quartz sometimes appearing in the ground-mass; in other cases the whole rock is silicified by substitution of quartz. Chalcedony, and more rarely opal, is also found in the altered rock. In many cases, in the deeper parts of the veins, the only difference between the rocks adjoining and those more distinct from the vein is in

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\* *Boletín del Instit. Geol. de Mexico*, Nos. 7, 8, 9. "El Mineral de Pachuca."



the quantity of impregnating silica. The pyroxene alters to chlorite and epidote. The feldspars (oligoclase and labradorite) are often converted to calcite, epidote and quartz. Mr. Ordoñez says further that the feldspars have a marked tendency to become transformed into kaolinite (*arcilla*). As he gives no analyses of the altered rocks, it is difficult to judge whether finely divided sericite is present or not. On the whole, the similarity of this district to the Comstock, so far as the alteration is concerned, is very striking; and there is little doubt that the two deposits owe their origin to extremely similar solutions.

*New Zealand.*—The auriferous veins of Thames, New Zealand, are contained in andesitic rocks, which, near the fissures, have suffered considerable alteration. The character of this alteration has been described by F. W. Hutton\* in a report on the rocks of the Hauraki gold-fields, which include, among others, the Thames district, and are situated near Auckland on the northern island. Triassic or pre-Triassic sediments are unconformably overlain by younger volcanic formations which contain the gold-deposits. The rocks consist largely of andesite, both augitic and hornblendic, which is accompanied by masses of tuffs and breccias. Rhyolite and dacite also occur. The alteration, chiefly of propylitic character, is distinguished by the appearance of much secondary chlorite, not only in the bisilicates but also in the ground-mass and in the feldspars, the latter besides, altering to calcite and "kaolin." The chlorite alters again, in places, to a mineral which, from the description of the author, probably is sericite. Another common secondary product is quartz in fine aggregates. The pyrite frequently, though not always, present, is sometimes derived from magnetite. In other cases it is associated with the product of decomposition of titaniferous iron-ore, usually referred to as leucoxene. The color of the rocks subjected to the propylitic alteration is greenish gray, which, on further alteration, changes into lighter tints. The process is illustrated by several analyses by Skey, but they only throw an imperfect light upon the subject, as the alkalis are not separated, nor  $\text{CO}_2$  and  $\text{H}_2\text{O}$  individually determined.

Prof. Hutton is a pronounced advocate of lateral secretion, and believes that the gold was derived from the surrounding volcanic rock. This conclusion is disputed by Dr. Don.†

\* *Austral. Ass. Adv. Sci.*, vol. i., 1887, pp. 245-274.

† "The Genesis of Certain Auriferous Lodes," *Trans.*, xxvi., 586.



*Alaska.*—The Apollo mine on Unga Island, described by Mr. G. F. Becker,\* is an interesting deposit in andesitic rocks. The ores consist of pyrite, galena, zinc-blende, chalcopyrite, with a little calcite. Native gold and copper occur with these ores, and the presence of a small quantity of orthoclase has also been proved. According to Becker, the ore is present exclusively as the filling of cavities, and shows beautiful comb-structure. In the vicinity of this deposit, the andesites are highly chloritic and contain abundant pyrite. Neither sericite nor carbonates are mentioned. The course of the alteration is very clearly propylitic. The pyrite in the altered rock is largely derived from the ferro-magnesian silicates.

*Silver Cliff, Colorado.*—The deposits of Silver Cliff should probably be referred to the propylitic class, although sericitization here also appears as a very important metasomatic characteristic. The districts of Silver Cliff and the Rosita Hills, as described by Messrs. Emmons and Cross,† are characterized by a complex of andesites, rhyolites and trachytes, resting on old Archean rocks and erupted through them. The igneous rocks and, to some extent, the old gneisses are traversed by a system of veins and irregular deposits carrying chiefly silver-ores, consisting of tetrahedrite, stephanite, pyrite, chalcopyrite and galena, in a gangue of barite with a little calcite. The ore consists chiefly of altered country-rock in which the different sulphides and gangue-minerals have been developed by metasomatic replacement. Mr. Emmons considers that the solutions first filled narrow fissures between sheeted rocks, and from these fissures gradually worked into the rock itself. The whole occurrence at Silver Cliff appears to show strong analogy with that of Cripple Creek and Nagyág; for in all of these places a relatively small complex of Tertiary eruptive rocks, at or near the point of eruption, has been traversed by a complicated system of fractures along which the ore has been deposited by solutions penetrating the fissures, as a later manifestation of the eruptive activity.

Over large areas the rock, especially the andesite, is much decomposed and bleached, and also contains a considerable

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\* 16th Ann. Rept. U. S. Geol. Surv., part iii., p. 83.

† 17th Ann. Rept. U. S. Geol. Surv., part ii., pp. 269-472.



amount of pyrite. The greenish color first appearing is due to the development of chlorite, the pyroxene being replaced by chlorite, calcite and quartz. Further alteration results in a strong sericitization, and in removal of iron and lime. The biotite always changes into muscovite, which sometimes contains crystals of anatase. The lime-soda feldspars are also replaced by aggregates of muscovites, but the potash-feldspars are rarely altered until all the other minerals have been almost completely decomposed. The magnetite disappears with the silicates. Pyrite is common, and in certain cases seems to be a direct replacement of magnetite. Calcite is frequently associated with muscovite, and may replace plagioclase or augite. Mr. Cross recognized no kaolin in noteworthy amount among the products of alteration. In some instances the bleaching extends through large rock-masses, but it clearly proceeds from fissures. Near the veins, the bleached rock adjoining the small fissures may gradually shade off into fresh rock within a few feet.

A silicification is noted in some cases, especially in the case of a dike of rhyolite,\* which has suffered so great alteration as to be almost completely changed to quartzose fine-grained material. The andesite may also occasionally show silicification. The rhyolite is altered in some places to soft, whitish material, and in other places to hard cavernous quartzose material. The contacts of rhyolite and andesite are sometimes changed to such a degree as to make rock-determination very difficult.

*Silver City, Idaho.*—The fissure-vein of the Trade Dollar and Black Jack mines, Florida mountain, near Silver City, Idaho, presents some unusual features.† The sharply defined vein cuts across granite, basalt and rhyolite. The ores consist of argentite and chalcopyrite in a gangue of quartz and valencianite (orthoclase), forming typical fillings of open spaces. The alteration affects the various rocks somewhat differently; but the vein is undoubtedly of the propylitic class, in the formation of which alkaline carbonates and carbon-dioxide were present only in small amounts.

In the granite the adjoining rock is very slightly altered, though spaces of dissolution and crushed portions in it may be filled with quartz and valencianite.

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\* *Loc. cit.*, p. 358.

† W. Lindgren, 20th Ann. Rept. U. S. Geol. Surv., pp. 134-144, 174-187.



The rhyolite is extensively altered and somewhat silicified, the quartz crystals having received aureoles of the same mineral in secondary deposition. The feldspars are often converted into fine-grained quartz and sericite, the ground-mass being changed to the same minerals, and the quartz predominating. A little kaolinite is probably also present, and pyrite in small cubes is scattered through the rock. Near the underlying basalt, epidote and chlorite have been introduced into the rhyolite, indicating an upward movement of the solution.

The basalt is also considerably altered, and the character is typically propylitic, with abundant chlorite and pyrite, and slight changes otherwise in the chemical constitution.

#### 6. *Fluoritic Gold-Tellurium Veins.*

This peculiar and interesting class of deposits, the discovery and study of which date only a few years back, is characterized by the appearance of tellurides of gold and silver, besides a little native gold; by the universal presence of (usually purple) fluorite; and by an intense metasomatic action—so that the larger proportion of the ores consists of altered country-rock. The gangue is quartz, fluorite and barite; ore-minerals, except tellurides, are not very abundantly present.

The age of these deposits, as thus far known, is probably Tertiary, following the outbreaks of phonolitic magmas, with which all of the occurrences show a remarkable connection. The depositing waters must have been poor in carbon-dioxide, alkaline and earthy carbonates, but contained more or less fluorine as hydrofluoric acid, which is possibly indicated by the abundant spaces of dissolution in the granite of Cripple Creek. Or else (and this was probably the more common case) they contained alkaline fluorides. Though the veins are closely connected with the eruption of phonolitic magma referred to, it is not believed that the conditions of deposition were of pneumatolytic character, but rather that they were normally hydrothermal.

*Cripple Creek.*—The geology and mineral deposits of the Cripple Creek district, Colo., have been examined by Whitman Cross and R. A. F. Penrose.\* The general occurrence of the veins is somewhat analogous to that of Nagyág, Hungary, and

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\* 16th Annual Report U. S. Geol. Surv., part ii.



Silver Cliff, Colorado, inasmuch as they cut igneous masses, here consisting of andesite and phonolite, and occur in close proximity to the original *locus* of eruption of these rocks. The veins, of which there are a great number, contain native gold, tellurides and pyrite, together with a little galena and zincblende. Silver is present in very small amounts only. The gangue consists of quartz, fluorite and barite. Prof. Penrose designates the veins as very largely replacement veins, formed by metasomatic action of the solutions ascending in narrow fissures on the surrounding country-rock. Filling of open fissures exists to a subordinate extent. Large masses of the volcanic rocks, especially the porous tuffs, were subjected to thermal action prior to the formation of some of the fissures. The alteration results in silicification, kaolinization and some sericitization. In the breccia and tuff, the process consists in the total destruction of the dark silicates, and the substitution of a white mica for them. The feldspar changes to muscovite or kaolin; the only fresh remaining crystals consist of apatite; and the rocks are greatly impregnated with pyrite. In some places the alteration consists in a silicification, but more commonly muscovite or kaolin are the minerals formed. Penrose says also that kaolin occurs in the veins in irregular masses, mixed with quartz. Three analyses of this product show that it is a normal kaolin. While it is conceded that the kaolin is to some extent the result of surface alteration, its formation was chiefly earlier than the development of this superficial alteration. The quantity of kaolin, he says, does not diminish in depth, where it still occurs associated with unaltered sulphides.

An opaline silica is also found in the veins, often appearing like red, brilliant, conchoidal jasper. An analysis of it shows:  $\text{SiO}_2$ , 72.46;  $\text{Al}_2\text{O}_3$ , 2.52;  $\text{Fe}_2\text{O}_3$ , 17.88;  $\text{CaO}$ , 0.14;  $\text{MgO}$ , trace;  $\text{K}_2\text{O}$ , 1.08;  $\text{Na}_2\text{O}$ , 0.06;  $\text{H}_2\text{O}$ , 5.70; total, 99.84 per cent.

The origin of this product is not stated, but it is not improbably the result of extreme alteration of a volcanic rock. It is interesting to note that among the alkalis  $\text{K}_2\text{O}$  strongly predominates, and, to judge from the analysis, the rock must contain about 10 per cent. of sericite.

During the last year I had opportunity to examine a suite of specimens collected by Mr. S. F. Emmons from the Independence and Portland mines; and some of the results are here



published with his permission. At these mines, the narrow fissure along which the replacement took place cuts both the granite and the andesite-granite breccia, and in places follows a dike of phonolite. The specimens clearly bear out previous statements as to replacement. In addition to the fluorite, secondary orthoclase, or valencianite, was recognized as a universally present gangue-mineral. The granite-ore from both mines consists of a coarsely granular rock, largely of microcline and quartz, made cellular and porous by spaces of dissolution. The cavities are coated with abundant small and clear crystals of valencianite showing the usual combination of prism and dome; also with a little pyrite, gold, and small cubes of fluorite.\* The crystals of valencianite were isolated and conclusively identified by qualitative analysis and tests. Microscopic analysis reveals but little alteration in the granite, though the biotite foils are replaced by a substance which appears to be valencianite. The feldspars contain a few shreds of sericite, and pentagonal crystals of pyrite are scattered through feldspar and altered biotite. In places, small replacement-veinlets of fluorite and quartz traverse the feldspar. The cavities of dissolution apparently result from the removal of both quartz and microcline. Some of them are filled with quartz, valencianite and pyrite; the secondary feldspar often being deposited with orientation parallel to that of older grains. A few grains of secondary feldspar show microcline structure, but most of them are simple individuals. These filled spaces, characterized by crustification, are illustrated in Fig. 11.

The processes of replacement are remarkably variable. In some of the granite-andesite breccias the result is quartz, valencianite, fluorite and pyrite. Fig. 10 shows how the replacement progresses in a grain of orthoclase. Fig. 8 shows a filled veinlet in the same breccia, which by means of a narrow crack connects with the feldspar grains just mentioned. The valencianite shows crustification, while the fluorite and pyrite, by corroding the walls, indicate partial metasomatic action.

Some of the phonolites of the Independence mine are porous siliceous rocks, completely replaced with quartz, valencianite crystals, pyrite, and a few grains of a telluride of gold and

\* Confer: W. Lindgren, "The Gold and Silver Veins of Silver City," 20th *Ann. Rept. U. S. G. S.*, part ii., p. 167.



silver. Other specimens show only incipient alteration, being impregnated with pyrite crystals and containing a few per cent. of sericite; they contain, besides, spaces of dissolution filled with quartz, fluorite and valencianite. Certain fine-grained granitic breccias from the Annie Lee shoot, in the Portland mine, show a most peculiar alteration, the quartz and orthoclase being both replaced by calcite, pyrite and secondary orthoclase. The final result of the alteration of phonolite is, in many cases, a purple fine-grained rock consisting of quartz, fluorite and pyrite; as usual, the fluorite is crystallized; and the quartz also shows, to some extent, idiomorphic outlines (Fig. 9).

*Other Occurrences.*—To this class belong also the so-called Potsdam tellurium-ores of the Black Hills, Dakota, described by Devereux, Carpenter, F. Clemes Smith, and lately by J. D. Irving.\* According to Mr. Irving, the irregular deposits are connected with fissures, and consist in a replacement of limestone by silica, with fluorite, and gold, partly in the form of tellurides. While the age of these deposits is not fully known, they are believed to be genetically connected with phonolitic and tinguaitic dikes of Tertiary age.

Mr. W. H. Weed† has described interesting occurrences of the same type from the Judith mountains in northern Montana. The deposits, though, strictly speaking, not fissure-veins, are still more or less clearly connected with fractures, and are found in the brecciated contact-zone between limestone and intrusive masses of acidic porphyry. The principal gangue-minerals are quartz and purple fluorite, the ore-minerals being native gold and tellurides of gold and silver. The mode of ore-deposition is certainly a replacement of limestone, the fluorite occurring in more or less sharply defined patches in the limestone breccia. From a specimen which Mr. Weed kindly selected for me a section was cut, which is partly illustrated in Fig. 14. The invasion of the normal limestone, still carrying organic remains, by the crystallizing fluorite, is well shown, as well as the incipient silicification which accompanied the metasomatic action. Much secondary silica, replacing limestone,

\* "A Contribution to the Geology of the Northern Black Hills," *Ann. N. Y. Acad. Sci.*, vol. xii., No. 9, pp. 297-314.

† 18th *Ann. Rept. U. S. Geol. Surv.*, part iii., p. 588.



also occurs in jaspery or cherty form. Small cubes of fluorite, found in the fresh limestone, represent places of incipient fluoritization. Dikes and sheets of phonolitic rocks are found in the vicinity of the deposits. A deposit occurring in rhyolite porphyry not far from the limestone shows strong alteration of the country-rock. The feldspar is here changed to sericite, the ferro-magnesian minerals are transformed to calcite, and abundant small crystals of pyrite appear in the rock. Fluorite is also present on some of the veins in rhyolite porphyries. Mr. Weed regards the deposits as possibly of pneumatolytic origin. It is scarcely necessary, however, to assume the fluorine to have been present in the form of free hydrofluoric acid (compare pp. 24 and 27).

Similar deposits, with purple fluorite and tellurides, are also described by Mr. Weed from the Little Rocky Mountains, in Montana.\*

#### 7. *Sericitic and Kaolinitic Gold- and Silver-Veins.*

*General Remarks.*—This class has not been studied as much as some of the other subdivisions, but many deposits will probably be found to belong to it. Apparently the pure aluminic silicate cannot be formed when the generating waters contain much carbon dioxide or alkaline carbonates. But it does form under the influence of some waters containing a small amount of these reagents, and also in the presence of sulphuric acid, which, as is well known, rapidly attacks the feldspars. Even under the latter two conditions, some sericite is ordinarily also formed; and I am not aware of any veins in which kaolinite forms without sericite. The class may be subdivided according to the absence or presence of silicification.

*The Freiberg Veins.*—As is well known, several very different kinds of veins appear in the Freiberg district, practically all, however, being sharply defined fissure-veins in gneiss, in which the filling of open spaces constitutes the only ore; extensive zones of alteration are absent. It is a peculiar fact that very little is known of the metasomatic processes affecting the country-rock at this celebrated locality, no chemical examinations having been made to determine how the various classes of

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\* *Journal of Geol.*, vol. iv., pp. 399-428 (1896).



veins may differ in their metasomatic products. A letter from Prof. Beck, of Freiberg, informs me that Prof. A. W. Stelzner devoted much time during the last years of his life to the examination of the changes in the country-rock adjoining the veins, but that his manuscript notes have never been published.

W. Vogelgesang,\* in describing the veins south and southeast of Freiberg containing carbonates and rich silver-ores, describes the impregnation of the adjoining rock with ores. He mentions the occasional introduction of argentite and native silver into the gneiss, also, in places, of arsenopyrite, pyrite, chalcopyrite, zinc-blende and galena. The impregnation with silver-ores appears only in especially rich places along the vein. In one case, however, the impregnated rock appears as an irregular, limited mass, almost entirely independent of the direction of the vein. In another locality, chalcopyrite and bornite were found in the wall-rock, while the filling of the vein contained neither. In the same paper, the author describes the alteration of the so-called normal gneiss of Freiberg near the veins of the *Kiesige Bleiformation*. The mica is the first mineral attacked; the second is the feldspar. The former acquires a silvery-white color, often connected with a chloritic appearance. The feldspar is changed to a white "kaolin," and the whole rock is bleached white. By extreme alteration, the quartz disappears, and the rock forms a white or yellowish-white talc-like mass. The altered rock is frequently, in fact usually, filled with arsenopyrite. Some of the crystals are large; others microscopic; and their amount may so increase as to form a connected, compact mass of arsenopyrite. All these crystals are twins, excellently developed, with perfect faces. This description refers especially to the *Dietrich Stehender* vein.† In the foot-wall, and partly also in the hanging-wall, of this altered mass appears a rock, recognizable as the ordinary grey gneiss of Freiberg. It contains no arsenopyrite but is strongly impregnated with galena, arranged in curved streaks parallel to the schistosity, and replacing one constituent of the rock, namely, the feldspar. The altered rocks have been analyzed; but the determination of alkalies being omitted, the analyses have no special value.

\* Bernard Cotta, *Gangstudien*, vol. ii., Freiberg, 1864, p. 78.

† The sericite from this vein has been analyzed by H. Schulze; see page .



The rock adjoining the Gotthold-Stehender vein is likewise strongly impregnated; but here, besides arsenopyrite, galena, chalcopyrite, pyrite and zincblende are also found.

Already in 1883 and 1884 Stelzner\* devoted considerable attention to the examination of the soft and altered rock adjoining the veins of Freiberg. These altered rocks are also usually impregnated with small crystals of arsenopyrite, or pyrite, or (more rarely) zinc-blende and galena. In the normal gneiss of Freiberg, which Prof. Stelzner subjected to separation by heavy solutions, he found much zircon, as well as a little tourmaline and a large quantity of apatite. All three of these minerals were also separated from the altered wall-rocks in the crystalline shape which they had had in the fresh rock; hence none of them had been attacked. He observes further that the quartz, feldspar and biotite of the fresh gneiss is completely or almost completely changed into white potassium mica, forming, in small hexagonal or irregular foils, the chief mass of the rock. This secondary mica contains, according to analysis by Dr. Schulze, as much as 0.41 per cent. of  $\text{TiO}_2$  and 0.54 per cent. of  $\text{SnO}_2$ . As newly-formed minerals in the altered rock, appear small crystals of quartz, rutile and anatase. In certain of the examined rocks only rutile was found, in others only anatase (octahedrite), but both were present as sharply defined small crystals. These two minerals are considered as resulting from a decomposition of the biotite, which is rich in titanitic acid. In analyzing the heaviest part obtained by the Thoulet solution from the altered rock close to one of the veins, it was found that cassiterite was present in notable quantity. Whether this tin-ore resulted from the decomposition of the biotite, or whether, like the arsenopyrite, it had been introduced from the vein-fissure, is not certain. The latter hypothesis is probable; for the black zinc-blende of the same vein (the Carl Stehender) contains small, but numerous, crystals of cassiterite.

Examination of the fresh gneisses of Freiberg discloses the presence of pyrrhotite, pyrite, and probably also a little arsenopyrite. These are presumably primary; at least the statement of Prof. Stelzner is probably to be interpreted in this sense.

The first attempt to examine the altered wall-rocks in a sci-

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\* A. W. Stelzner, "Studies of the Gneiss of Freiberg and its Products of Alteration." *Neues Jahrbuch*, 1884, vol. i., p. 271.



entific manner was made by Prof. T. H. Scheerer,\* in connection with his classic paper on the gneissic rocks from the vicinity of Freiberg. According to Scheerer, the normal character of the grey gneiss is always more or less changed in the vicinity of mineral veins, the extension of this alteration being, in general, dependent upon the width of the vein. The mica has turned into a light greenish-grey or white talcose mass; and the whole rock is softened and easily crushed. The width of this alteration ranges from a few inches up to 6 feet. In the porous gneiss, small bodies of pyrite, zinc-blende and galena have been formed; partly as separate crystals, and partly in little veinlets. Prof. Scheerer examined especially a gneiss closely adjoining the Erzengel vein belonging to the *Kiesige Bleiformation*, in the Himmelfahrt mine. The specimen was taken from one of the deep levels, thus eliminating the action of surface-water. The analysis gave:  $\text{SiO}_2$ , 61.69;  $\text{TiO}_2$ , 0.73;  $\text{Al}_2\text{O}_3$ , 21.74;  $\text{Fe}_2\text{O}_3$ , 0.43;  $\text{CaO}$ , 1.07;  $\text{MgO}$ , 1.15;  $\text{K}_2\text{O}$ , 2.69;  $\text{Na}_2\text{O}$ , 0.30;  $\text{H}_2\text{O}$ , 3.96; fluorite, 1.20; pyrite, 4.26; chalcopyrite, 0.23; galena, 0.09; argentite, trace; total, 99.54 per cent.

Scheerer recalculated this analysis on the basis of constant alumina and, combining the result with the analyses of the fresh rock, obtained the following table (see page 85). The assumed constancy of the alumina is probably not quite correct, but offers an easy and fairly accurate way of approximately judging the changes that have taken place.

This result is remarkable in many respects. First, we note that a very decided removal of substance has taken place. Counting by equal weights, only 5 parts in 100 have been added (even less, if we consider that the Fe of FeS is derived from  $\text{Fe}_2\text{O}_3$  and FeO in the fresh rock) while no less than 42.45 parts have been carried away. This contrasts strongly with the results obtained from gold-quartz veins in California and Idaho. Of the silica, 26.62 parts or 40 per cent. is removed. The total bases, except alumina, have been diminished to the extent of 81.01 per cent. Both  $\text{K}_2\text{O}$  and the  $\text{Na}_2\text{O}$  have been removed; the former, however, in much smaller proportion than the latter. Lime, magnesia and iron have also been very greatly reduced. A large part of the iron, however, appears to

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\* *Zeitschr. d. d. Geol. Ges.*, vol. xiv., p. 87.



	Normal Gray Gneiss.	Altered Gray Gneiss.	Additions and Subtractions Suffered by the Altered Rock.
	Per cent.	Per cent.	Per cent.
SiO <sub>2</sub> .....	65.42	38.80	-26.62
TiO <sub>2</sub> .....	1.05	0.46	-0.59
Al <sub>2</sub> O <sub>3</sub> .....	13.68	13.68	...
Fe <sub>2</sub> O <sub>3</sub> .....	4.26	0.27	-3.99
FeO.....	2.88	...	-2.88
CaO.....	1.44	0.67	-0.77
MgO.....	2.66	0.73	-1.93
K <sub>2</sub> O.....	6.18	1.70	-4.48
Na <sub>2</sub> O.....	1.38	0.19	-1.19
H <sub>2</sub> O.....	1.05	2.49	+1.44
Fluorite.....	...	0.76	+0.76
Pyrite.....	trace	2.68	+2.68
Chalcopyrite.....	trace	0.15	+0.15
Galena.....	trace	0.06	+0.06
Argentite.....	...	trace	trace
	100.00	62.64	-42.45
			+5.09
			37.36
		100.00	

have been transformed into pyrite. There are no carbonates at all, while a little fluorite has formed.

Of course, no microscopic diagnosis of Scheerer's specimens is now available. But from his later separations and Schulze's analysis it is clear that considerable sericite is present. An attempt to calculate Scheerer's analysis shows at once that kaolinite is also present. A rough calculation gives the following result: Quartz, 40; sericite, 32; chlorite, 3.20; kaolinite, 17.70; titanite, 1.90; fluorite, 1.20; pyrite, 4.26; chalcopyrite, 0.23; galena, 0.09; total, 100.58 per cent.

In this calculation  $K_2O + Na_2O$  are taken as a basis for sericite, according to Schulze's analysis; MgO is calculated as chlorite; the remaining H<sub>2</sub>O is calculated, with proper quantities of Al<sub>2</sub>O<sub>3</sub> and SiO<sub>2</sub>, as kaolinite; and there is a small excess of CaO, possibly belonging to apatite. P<sub>2</sub>O<sub>5</sub> is not determined in the analysis. But there remains also an excess of 4 per cent. of Al<sub>2</sub>O<sub>3</sub>, which is inexplicable on the basis of this assumed mineral composition; and it is difficult to see how this should be treated. Possibly the determination of H<sub>2</sub>O is a little too low. At any rate, a considerable amount of kaolinite is surely present. This result is of great interest. The strong leaching of SiO<sub>2</sub> and bases, as well as the presence of kaolinite together



with sericite, points to a process and to water very different from those by which sericite alone is produced. It is not out of place in this connection to call attention to the presence of fluorite and to the close relationship which, as indicated by Dalmer, exists between the cassiterite-veins and those of the *Kiesige Blei* formation of the Erzgebirge, a relationship still further emphasized by the occurrence of cassiterite in the Freiberg veins. Scheerer believed that the grey gneiss, by reason of its easily-attacked biotite, had a precipitating influence on the mineral waters. The red gneiss, containing muscovite in general, carries no large bodies of ore.

*De Lamar, Idaho.*—The quartz veins of De Lamar, Idaho, belong to that class in which the alteration of the country-rock results in sericite, kaolinite and quartz.\* These ores, which carry finely-divided gold, together with some rich silver minerals, are peculiar, because the quartz now constituting the filling is pseudomorphic after a former vein-filling of calcite. The country-rock has undergone two corresponding changes: the first consisting in a normal sericitization; the second in a silicification, probably under the influence of waters containing sulphuric acid. The final result is that the rhyolite is converted to a silicified rock, in which the structure is plainly preserved. The phenocrysts of quartz have received aureoles of secondary silica; and the feldspars are fully converted into fine-grained aggregates of quartz. The composition is as follows: Sericite, 15.43; kaolinite, 3.81; quartz, 78.73; pyrite, 0.90, and water (hygroscopic), 0.51; total, 99.38 per cent.

Expressed in percentages, the process appears to consist in the loss of nearly all of the soda, half of the alumina and much of the ferrous and ferric oxide; and finally, in the addition of several per cent. of silica. The pseudomorphic filling consists of crossing laminae of quartz, each consisting of a thin plate of microcrystalline silica, coated on both sides with small quartz crystals.

The character of the process involved in this change from calcite to quartz is probably as follows: Calcite-filling in veins is often characterized by a prevalence of long, slender or spear-shaped grains. The solutions carrying silica penetrate along

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\* W. Lindgren, 20th An. Rept. U. S. Geol. Sur., p. 178 et seq.



the contact-planes of these grains and deposit their plates of microcrystalline quartz in the place of dissolved calcite; from these medial plates small quartz crystals grow into and gradually replace the calcite on both sides. The pseudomorphic plates do not, as a rule, follow the cleavage-planes; hence there may be in some cases considerable difficulty in determining the original mineral replaced by the quartz. The subject is more fully treated in my report, cited above.

*Summit District, Colorado.*—Some remarkable ore-deposits in the Summit district, Rio Grande county, Colo., have been described by R. C. Hills\* as masses of quartz resulting from the alteration and silicification of eruptive rocks along contact-planes, especially between rhyolite and trachyte-breccia. The quartz, which contains gold, enargite, pyrite, galena and zinc-blende, gradually merges into rhyolite, varying in thickness from 3 to 30 feet. Thus silicification of the rhyolite is evident, and has resulted in a change of the ground-mass to compact quartz, while the phenocrysts of that mineral remain intact and conspicuous. The sanidine has been removed, and pseudomorphic quartz has been deposited. The surrounding rock is notably kaolinized, and contains no lime or potash. The alteration probably took place less than 300 ft. below the original surface.

The following is suggested in explanation of the chemical processes: Silica is practically insoluble in solutions containing sulphates and chlorides, hydrogen sulphide and free sulphuric acid. Under these conditions, aluminum silicates are dissolved and sulphates or chlorides of aluminum are formed, with simultaneous separation of silica; and to sulphuric acid as a reagent the writer believes the alteration to be chiefly due. Whether the metallic minerals were deposited simultaneously with this alteration, or subsequently, is left an open question, though it is believed that their simultaneous deposition would be possible.

#### 8. *Sericitic and Calcitic Gold-Silver Veins.*

This important metasomatic class comprises an enormous number of veins, differing widely in age and in the character

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\* *Proc. Colorado Sci. Soc.*, vol. i., p. 21.



of the country-rock, but usually characterized by quartz-filling, enclosing auriferous and argentiferous sulphides (often also free gold), while the adjoining rock for a short distance on both sides is converted into an aggregate of quartz, sericite and calcite, with some metasomatic sulphides. Extensive alteration-zones are not common; and sometimes fresh rock may adjoin the vein. The relative quantity of sericite and carbonates may differ considerably, even in the same mine.

*The Gold-Quartz Veins of California.*—These, perhaps the most prominent representatives of the class, have been studied in some detail.\* The gold-quartz veins of California are fissure-veins of Cretaceous age, largely filled with quartz along open spaces. A small amount of calcite may also occur. The ore-minerals comprise native gold, present in a free state at all depths reached hitherto, and a small amount of sulphides consisting of pyrite (never marcasite and rarely pyrrhotite), galena, zinc-blende, arsenopyrite and chalcopyrite. Tellurides are often found, but in small quantity only. The veins are practically independent of the character of the country-rock, cutting almost all the sedimentary and igneous rocks of the Sierra Nevada. Adjoining the veins the country-rock, for a variable distance, but seldom exceeding a few feet, is nearly always altered by metasomatic processes. Clay-slates and siliceous schists have been apparently least affected in this way, except that they are generally impregnated with pyrite. More detailed chemical examinations will probably show that even these rocks have been altered more than their appearance would suggest.

In the ordinary course of the metasomatic process, augite, hornblende, epidote, biotite and feldspars are first vigorously attacked. The ferromagnesian silicates are often converted into large foils of muscovite. The alteration proceeds along cracks and cleavage-planes, and a finely felted aggregate of sericite and calcite invades the grains until the replacement is complete. Though the ferromagnesian silicates are, for the most part, directly converted into the minerals mentioned, they form also a chlorite, very rich in iron, as an intermediate

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\* W. Lindgren, *Bull. Geol. Soc. Am.*, vol. vi., pp. 221-240; also in *U. S. Geol. Surv.*, 14th Ann. Rept., pp. 249 to 284, and 17th Ann. Rept., pp. 1 to 262.



stage, which is converted later into sericite. An interlacing structure of sericite foils, the triangular or polygonal interstices of which are filled with calcite (Fig. 12), is often noted. The quartz is also attacked, but with more difficulty; and in no case is it completely replaced by the attacking sericite-carbonate aggregate (Fig. 15). Magnetite seems to be converted mostly into ferrous carbonate, and ilmenite to rutile. Sharp cubes of pyrite form in the new aggregates, but also in the fresh primary minerals. The only other sulphide found is arsenopyrite, which, in some mines, appears as sharply defined rhombic crystals. The sulphides sometimes include fibers of sericite. The result of the process is the conversion of the rock to sericite, carbonates, quartz and pyrite, with retention of the original structure as shown in Fig. 27. The alteration of serpentine has already been referred to on p. 89.

From many analyses the following eight are selected, A and A<sub>1</sub>, B and B<sub>1</sub>, etc., being respectively the unaltered and altered rock from each locality :

TABLE I.—*Analyses of Metasomatic Rocks from Gold-Quartz Veins.*

	A.	A <sub>1</sub> .	B.	B <sub>1</sub> .	C.	C <sub>1</sub> .	D.	D <sub>1</sub> .
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
SiO <sub>2</sub> .....	65.54	46.13	45.56	37.01	66.65	56.25	51.01	45.74
TiO <sub>2</sub> .....	.39	.67	1.11	.85	.38	.25	.98	.36
Al <sub>2</sub> O <sub>3</sub> .....	16.52	15.82	14.15	12.99	16.15	17.65	11.89	5.29
Fe <sub>2</sub> O <sub>3</sub> .....	1.40	.89	1.20	.43	1.52	.76	1.57	.13
FeO.....	2.49	2.27	9.83	3.57	2.36	2.64	6.08	2.06
FeS <sub>2</sub> .....	.....	1.61	7.86	7.99	.02	2.87	1.73*	.49
Cu <sub>2</sub> S.....	.....	.....	.10	trace	.....	.....	trace	.....
MnO.....	.06	.09	.25	.24	.10	none	trace	.26
NiO, ZnO.....	.....	trace	trace	trace	.....	.....	.....	.....
CaO.....	4.88	10.68	2.30	9.78	4.53	4.46	10.36	23.85
SrO.....	not det.	trace	trace	trace	trace	.....	none	none
BaO.....	not det.	trace	trace	trace	.07	.03	none	trace
MgO.....	2.52	2.13	6.76	5.49	1.74	1.69	8.87	.94
K <sub>2</sub> O.....	1.95	5.30	1.18	4.02	2.65	6.01	.15	1.29
Na <sub>2</sub> O.....	4.09	.17	1.57	.13	3.40	.30	4.17	.11
Li <sub>2</sub> O.....	.....	trace	trace	trace	trace	.....	.....	trace
H <sub>2</sub> O below 110° C...	.....	.12	.23	.13	.18	.30	.24	.22
H <sub>2</sub> O above 110° C...	.59	2.42	4.84	1.92	.72	2.36	2.09	1.07
P <sub>2</sub> O <sub>5</sub> .....	.18	.10	.14	.06	.10	.21	.17	.07
SO <sub>3</sub> .....	.....	.....	.03	.04	.....	.....	.....	.....
CO <sub>2</sub> .....	.....	11.24	3.04	15.04	.....	4.82	.....	18.91
Total.....	100.61	99.64	100.15	99.69	100.57	100.60	99.31	100.79

\* Probably present as Fe<sub>2</sub>S<sub>3</sub>.



A, Fresh granodiorite, Lincoln, Placer Co. Though not adjoining the vein, it indicates closely the actual composition of the fresh wall-rock. W. F. Hillebrand, analyst.—A<sub>1</sub>, Altered granodiorite, Plantz vein, Ophir, Placer Co. W. F. Hillebrand, analyst.—B, Amphibolite schist, Mina Rica vein, Ophir, Placer Co. Fairly fresh, but contains pyrite and calcite. W. F. Hillebrand, analyst.—B<sub>1</sub>, Completely altered amphibolite schist, Conrad vein, Ophir, Placer Co. W. F. Hillebrand, analyst.—C, Fresh granodiorite, Nevada City, Nevada Co. W. F. Hillebrand, analyst.—C<sub>1</sub>, Altered granodiorite, Bellefountain mine, Nevada City. George Steiger, analyst.—D, Fresh diabase, Grass Valley. N. H. Stokes, analyst.—D<sub>1</sub>, Altered diabase, North Star mine, Grass Valley. W. F. Hillebrand, analyst.

From the chemical and microscopical data the following compositions may be calculated (see reports cited). The only difference from the sources quoted is due to the fact that by later chemical examination the titanium mineral present has been shown to be rutile instead of titanite.

TABLE II.—*Mineralogical Composition of the Altered Rocks of Table I.*

	A <sub>1</sub> .	B <sub>1</sub> .	C <sub>1</sub> .	D <sub>1</sub> .
	Per cent.	Per cent.	Per cent.	Per cent.
Quartz.....	16.00	24.00	25.00	35.00
Sericite (with a little chlorite) .....	41.76	46.97	61.46	21.20
Calcite.....	17.53	18.87	7.23	42.15
Magnesite.....	9.67	2.93	2.70	.71
Siderite.....	5.76	3.67	.58	...
Rhodonite.....	.42	.14	...	...
Rutile.....	.85	.67	.25	.36
Pyrite.....	7.99	1.61	2.87	.50
Apatite.....	.13	.22	.46	.15
Total.....	100.11	99.08	100.55	100.07

As it seems probable that the alumina has remained fairly constant in the first three pairs of analyses in Table I., they may be directly compared for an approximate review of the chemical changes affected. A recalculation on the basis of constant alumina seemed scarcely worth while.

The silica has been in all cases greatly reduced. Except in A, which is not from the immediate vicinity of the vein of A<sub>1</sub>, the titanitic acid has decreased. Ferrous and ferric oxide are both reduced—the latter more than the former; and the whole or a part of this loss reappears as pyrite. Lime shows great increase except in C., where it is constant. Baryta in C shows partial loss. The loss of magnesia is considerable, except in C,



where it is slight. Potassa is strongly increased throughout; and there is a corresponding loss of soda.

D<sub>1</sub> differs from the rest in an exceptionally high percentage of introduced lime and carbon-dioxide, and a corresponding loss of magnesia. Moreover, the alumina is so low that removal of this constituent must be supposed to have taken place.

The characteristic features of the process seem to consist in the decrease of silica, magnesia and soda, and increase of lime, potassa and carbon-dioxide—this calcitic altered rock strongly contrasting with the quartz-filled veins. Sufficient data are not available for the accurate determination of change of volume during the process, and of the actual losses and gains. They could probably be determined by analyses and specific gravity determinations of very carefully selected samples of the fresh rocks, and of altered rocks immediately adjacent to them. It seems probable that, in most cases, the added material has more than balanced the losses.

*Idaho Types.*—In the Rocky Mountain region appear other types related to that of California. These gold-quartz veins cut granites, diorites and various porphyries, and, like the California veins, are of pre-Tertiary, probably Cretaceous, age. They carry a strong percentage of sulphurets, but generally only a subordinate amount of free gold, most of the gold being closely held in the sulphides. The filling constitutes the rich ore, but the narrow zone of metasomatic rock may also yield some low-grade ore. In general character, the metasomatic action is similar to that of the California veins, though the details of chemical change may differ. Galena, zinc-blende and chalcopyrite, and occasionally also free gold, may appear in the altered rocks. The carbonates are less plentiful, and lime is more often subtracted than added. The following analyses illustrate the chemical changes in two prominent types. E and E<sub>1</sub> are the fresh and altered rock from Willow Creek district, Boise county. The narrow quartz-veins carry scarcely any free gold, but much auriferous galena, pyrite, arsenopyrite and zinc-blende. F and F<sub>1</sub> are the fresh and altered rock from the Cræsus mine, Wood River district, Blaine county. The narrow streaks of filling here consist of quartz, siderite, pyrrhotite and chalcopyrite, with a little galena, arsenopyrite and zinc-



blende. Here again only a fraction of the gold is in free state. The ore contains very little silver.\*

TABLE III.—*Analyses of Fresh and Altered Rocks from Gold-Quartz Veins.*†

	E.	E <sub>1</sub> .	F.	F <sub>1</sub> .
SiO <sub>2</sub> .....	65.23	66.66	57.78	58.01
TiO <sub>2</sub> .....	.66	.49	1.01	1.08
Al <sub>2</sub> O <sub>3</sub> .....	16.94	14.26	16.28	15.72
Fe <sub>2</sub> O <sub>3</sub> .....	1.60	.67	1.02	.64
FeO.....	1.91	1.33	4.92	3.87
CoO, NiO.....	...	...	.02	none
MnO.....	trace	trace	.15	.17
CaO.....	3.85	3.37	6.65	2.15
SrO.....	...	...	.07	none
BaO.....	.19	none	.12	trace?
MgO.....	1.31	.95	4.60	2.07
K <sub>2</sub> O.....	3.02	4.19	2.22	4.79
Na <sub>2</sub> O.....	3.57	none	3.25	.10
H <sub>2</sub> O below 100° C.....	.18	.36	.34	.31
H <sub>2</sub> O above 100° C.....	.88	2.16	.92	2.71
P <sub>2</sub> O <sub>5</sub> .....	.19	.17	.30	.31
CO <sub>2</sub> .....	.25	3.67	.15	2.86
S.....	none	.95	.02	1.25
Fe.....	...	.84	...	1.52
Co, Ni.....	...	...	...	.12
Pb.....	...	...	...	.86
Cu.....	...	...	...	.05
As.....	...	...	...	1.65
Total.....	99.78	100.07	99.82	100.24

E. Fresh granitic rock immediately adjoining the Silver Wreath quartz vein, Willow Creek, Idaho. E<sub>1</sub>. Altered rock, adjoining the same vein. F. Fresh quartz-pyroxene-diorite, adjoining the Cræsus vein, Hailey, Idaho. F<sub>1</sub>. Altered rock adjoining the same vein.

The composition of the altered rocks may be calculated as shown in table on page 93.

The appearance of the altered rock F<sub>1</sub> from the Cræsus mine is shown in Fig. 25.

The specific gravity of E is 2.714. From the mineralogical composition given in the report quoted the specific gravity is calculated to 2.720, which is a close agreement, the difference possibly indicating a very slight porosity.‡

\* For full calculations and description of E and E<sub>1</sub> see W. Lindgren, 18th Ann. Rept. U. S. Geol. Surv., part iii., p. 640; for F and to F<sub>1</sub> see W. Lindgren, 20th Ann. Rept. U. S. Geol. Surv., part iii., p. 211-232.

† Analyst, W. F. Hillebrand.

‡ In this calculation the following figures for specific gravity are used: quartz, 2.65; sericite, 2.83; biotite, 3.00; oligoclase, 2.65; orthoclase, 2.56.



TABLE IV.—*Mineralogical Composition of  $E_1$  and  $F_1$ , in Table III.*

	$E_1$ .	$F_1$ .
Quartz .....	42.00	36.18
Sericite.....	46.84	38.18
Chlorite.....	...	11.76
Calcite.....	4.80	3.11
Magnesite.....	1.96	1.26
Siderite.....	1.45	2.19
Rutile.....	.49	1.08
Apatite.....	...	.72
Pyrite.....	1.78	.58
Pyrrhotite.....	...	.15
Zinc-blende.....	...	trace
Galena.....	...	.99
Chalcopyrite.....	...	.15
Arsenopyrite.....	...	3.58
Total.....	99.32	99.93

The measured specific gravity of  $E_1$  is 2.774, indicating that the rock alters to denser minerals. The calculation of the same specific gravity from Table IV. gives 2.796, which shows a decided porosity of the altered rock. Under these circumstances, no evidence of pressure being noted, it may be assumed with fair accuracy that no considerable change in volume has taken place; and by multiplying the percentages of E and  $E_1$  by 2.714 and 2.774 respectively, and comparing the results, the absolute gains and losses per cubic meter may be obtained (see Table V.).

In the same manner the measured specific gravities of F and  $F_1$  are compared with the calculated specific gravities.\* This shows that similar conditions prevail here, the porosity being greater. By multiplying the percentages of F and  $F_1$  by the measured specific gravities, and comparing these data, the absolute gains and losses are again obtained.

During the alteration of E to  $E_1$ , 291 kilograms were added and 229 lost per cubic meter; the net total being a gain of 62 kilos. During the alteration of F to  $F_1$ , 416 kilograms were added and 333 lost per cubic meter; the net total being a gain 83 kilos.

A perusal of the table will show very similar results in the

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\* 20th Ann. Rept. U. S. Geol. Surv., part iii., pp. 211-232.



TABLE V.—*Gains and Losses per Cubic Meter of E and F, Table III.*

	E.				F.			
	GAIN.		LOSS.		GAIN.		LOSS.	
	Per Cubic Meter of E.	Percentage of, for Each Constituent.	Per Cubic Meter of E.	Percentage of, for Each Constituent.	Per Cubic Meter of F.	Percentage of, for Each Constituent.	Per Cubic Meter of F.	Percentage of, for Each Constituent.
	Kilos.	Per cent.	Kilos.	Per cent.	Kilos.	Per cent.	Kilos.	Per cent.
SiO <sub>2</sub> .....	79	4.5	...	...	48	2.9	...	...
TiO <sub>2</sub> .....	...	...	4	22.2	2	6.9	...	...
Al <sub>2</sub> O <sub>3</sub> .....	...	...	64	13.9	...	...	4	.9
Fe <sub>2</sub> O <sub>3</sub> .....	...	...	24	55.8	...	...	10	34.5
FeO.....	...	...	15	28.8	...	...	27	19.4
CoO, NiO.....	...	...	...	...	...	...	1	100.0
MnO.....	...	...	...	...	1	25.0	...	...
CaO.....	...	...	11	10.5	...	...	126	67.0
SrO.....	...	...	...	...	...	...	2	100.0
BaO.....	...	...	5	100.0	...	...	4	100.0
MgO.....	...	...	9	25.7	...	...	70	53.9
K <sub>2</sub> O.....	34	41.5	...	...	76	120.6	...	...
Na <sub>2</sub> O.....	...	...	97	100.0	...	...	89	96.7
H <sub>2</sub> O above 105° C.....	36	150.0	...	...	53	203.8	...	...
P <sub>2</sub> O <sub>5</sub> .....	0	...	0	...	0	...	0	...
CO <sub>2</sub> .....	93	nearly all.	...	...	79	nearly all.	...	...
S.....	26	all.	...	...	35	nearly all.	...	...
Fe.....	23	all.	...	...	44	all.	...	...
Co, Ni.....	...	...	...	...	4	all.	...	...
Pb.....	...	...	...	...	24	all.	...	...
Cu.....	...	...	...	...	2	all.	...	...
As.....	...	...	...	...	48	all.	...	...
Total.....	291		229		416		333	

two rocks: a moderate addition of silica and a strong gain of potassa; nearly complete loss of soda, baryta and strontia; partial loss of alumina, magnesia and lime, F, however, losing much more lime than E. In E<sub>1</sub> the amounts lost of Fe<sub>2</sub>O<sub>3</sub> and FeO are nearly completely converted into Fe (in FeS<sub>2</sub>). In F these losses are less and not sufficient to account for the gain of Fe; consequently iron must have been added. Phosphoric acid is constant, consistently with the fresh state of the apatite.

*San Juan, Colorado.*—In the San Juan region, southwestern Colorado, are vast eruptive masses of andesites and rhyolites,



with their accompanying tuffs and breccias. Some of the gold-quartz veins of Tertiary age occurring in these rocks at Telluride have been described by Mr. C. W. Purington.\* The ores consist of quartz containing native gold, with pyrite, galena and other sulphides. In some localities silver is also present in considerable amount. The principal gangue is quartz, though carbonates also are occasionally present, and fluorite in considerable quantities is mentioned from the Tomboy vein. This is worthy of note; since, in ordinary gold-quartz veins fluorite, if not entirely absent, at least is exceedingly rare. The quartz forms, as a rule, a well-defined filling of open cavities, and the principal ore is of this character, and not altered country-rock. There are, however, more or less wide zones of partial alteration alongside the veins. The veins are often accompanied by large amounts of white, soft clay-like material, which probably is extremely altered country-rock. All of this appears to be sericite. Mr. Purington mentions having failed to establish the presence of kaolinite, except in one or two places. The ordinary course of alteration in the diorites, andesites and breccias is distinguished by the development of much calcite and sericite, and is consequently very similar to the metasomatic processes characterizing the California quartz-veins. The altered rocks contain small, abundant and sharply defined crystals of pyrite, more rarely of galena. Much of this pyrite fills the spaces formerly occupied by ferro-magnesian silicates. This pyrite is of low value, compared with the massive mineral occurring in the vein-filling. The percentage of silica in the altered rock is low, and contrasts with the abundant quartz on the veins.

Rhyolite adjoining the veins is changed to felted sericite and some carbonates, as well as pyrite.

As an exceptional process Mr. Purington mentions a complete silicification of the diorite from the hanging-wall of the Butterfly vein, in the Terrible mine. This diorite, which consists of labradorite, hornblende and a little biotite, shows a complete replacement of the feldspar by cryptocrystalline silica, while the hornblende is replaced by pyrite. There is a little sericite, but no carbonate present. The cause of this abnormal altera-

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\* 18th Ann. Rept. U. S. Geol. Surv., part iii., pp. 745-846.



tion might be in a local occurrence of waters in which the  $H_2S$  had been oxidized to  $H_2SO_4$ . A partial analysis of the silicified diorite runs as follows :

	Per cent.
$SiO_2$ , . . . . .	70.30
$Al_2O_3^*$ , . . . . .	20.00
$MgO$ , . . . . .	0.31
$CaO$ , . . . . .	0.27
$K_2O$ , . . . . .	1.78
$Na_2O$ , . . . . .	0.64

The large percentage of alumina indicates the presence of kaolinite, so commonly accompanying silicification. Sericite is also present.

A further instance of silicification in part, probably, due to cementation, is mentioned in the case of certain sedimentary rocks adjoining the vein. Here again it is accompanied by a development of pyrite; and the silicification extends to a distance of 15 feet from the vein.

*The Treadwell Mine, Alaska.*—According to Mr. G. F. Becker,† the country-rock of the celebrated Treadwell mine consists of a sodium syenite, which is strongly altered and traversed by small seams, carrying a value chiefly in gold. The whole mass of seams and country-rock is mined and milled. The process of alteration consists in a change of the albite, which is the predominant mineral, into carbonates and pyrite. Sericite is also present, as well as a little chlorite.

*Gold-Veins of Ontario, Canada.*—Peter McKellar‡ describes quartz-veins in granite of Western Ontario at Lake of the Woods, which are supposed to be of Archean age. The quartz-veins are only from 3 to 4 in. wide containing auriferous sulphides of copper, lead, zinc and bismuth. These narrow veins are adjoined by from 2 to 5 ft. of altered granite, largely consisting of a greenish fine-grained mineral, probably sericite. Some of this altered granite contains gold, and from 0.5 to 3 per cent. of auriferous pyrite, while the above mentioned sulphides rarely appear in it. The principal ore consists of this altered rock.

*Swarzwald Fissure-Veins.*—Much material of interest relating to the alteration of country-rock is found in the well-known

\* Including  $Fe_2O_3$ ,  $TiO_2$ , and  $P_2O_5$ .

† 18th Annual Report U. S. Geol. Surv., part iii., p. 64.

‡ Trans., xxix., 104 (1899).



investigations of Prof. Sandberger.\* In his discussions, as may be expected, superficial weathering is not always strictly separated from deep-seated alteration. In the fissure-veins of Schapbach, in the Schwarzwald, biotite of the granitic country-rock yields a chlorite rich in iron and a substance supposed to be pilite. The decomposition (alteration ?) of the gneiss in the same districts yields a mineral which Sandberger calls hygrophilite, derived from the alteration of oligoclase. It has a specific gravity of 2.70, and is closely allied to muscovite, if not identical with it. The alteration of the schistose gneiss near the veins, involving a formation of hygrophilite from oligoclase, shows a concentration of  $K_2O$  and a decrease of  $Na_2O$ . In one instance a conversion to carbonates was also noted. For a certain distance on both sides of the veins the rock is softened and altered. The extent of this alteration, which is supposed to be favorable to the occurrence of rich ore-bodies, corresponds to the extent over which its principal leaching has taken place. Sandberger thus derives the minerals of his veins directly from the adjoining country-rock. He further says:†

“It is of the greatest importance for the understanding of the veins occurring in this granite area to examine the alterations which the rock has suffered by means of waters containing carbonic acid, and by means of weathering with free access of atmospheric oxygen.”

In the silver-veins of Wittich, Schwarzwald, Prof. Sandberger finds that the alteration of the biotite is accompanied by the separation of  $TiO_2$  as anatase or brookite. The oligoclase is transformed to a kind of pinitoid which Sandberger calls lepidomorphite, and which may simply be an impure and microcrystalline muscovite. Two analyses are given‡ of fresh and altered granite, the latter occurring close to a vein. The composition of the altered rock is almost the same as that of the fresh, except that a little iron, somewhat over one per cent. of lime, and an equal amount of magnesia, have been carried away. The potash remains practically constant, while about one-half per cent. of soda has been lost. The silica has suffered an increase of 2.5 per cent., the alumina of 1 per cent. Sandberger remarks with good reason that these slight changes

\* *Untersuchungen über Erzgänge*, i. and ii.

† *Op. cit.*, ii., p. 343.

‡ *Op. cit.*, ii., p. 347.



could very well have been effected by waters containing a little carbon dioxide.

Near the vein of Wittichen the ore-minerals are not confined to the fissure, but are also present to a remarkable extent in the altered rock adjoining it. The gangue is here quartz, barite, calcite and fluorite. The ores consist of native silver and various cobalt-minerals. The ore-minerals mentioned, accompanied by small crystals of chalcopyrite, occur abundantly in the altered granite. The veins traverse not only the granite but also the overlying Permian formation, although in these horizontal rocks they lose their mineral contents almost completely. They are rich only in the altered granite, the oligoclase and mica of which have been completely, and the orthoclase partially altered. It is acknowledged that these veins were formed when 1500 feet of rocks rested on the granite, and that consequently the temperature and pressure must have been higher than at the surface. In conformity with Prof. Sandberger's well-known views, the sulphides occurring on the veins are explained by reduction of sulphates.

The veins of Schapbach may be compared with those described from the Central Plateau of France by Daubrée. The similarity in occurrence, gangue and ores is very striking; only, in the case of the latter we have undoubted proof of their intimate connection with actual ascending springs.

#### 9. *Silicic and Calcitic Cinnabar-Veins.*

The quicksilver-deposits of the Pacific Coast have been described by Mr. G. F. Becker.\* The cinnabar occurs chiefly in zones of fracture or in fissure-veins, and is almost always associated with quartz and chalcedonic aggregates. Opal is very commonly present in the ores, but the sulphide of mercury is very rarely if ever directly imbedded in it. The main deposit of opal preceded that of cinnabar and quartz.

Various rocks, such as diabase, diorite and serpentine, are adjacent to the quicksilver-veins. These rocks are nearly always more or less altered and converted into dolomitic carbonates. Many of them are also silicified, being converted into opal. Serpentine especially is often transformed in this man-

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\* Monograph XIII., *U. S. Geol. Surv.*



ner, and all transitions between the fresh rock and the pure opal may be found; the latter may retain the color and structure of serpentine. Certain glaucophanes from the Lake Quicksilver mine are altered into microcrystalline quartz. Although Mr. Becker recognizes the fact that the country-rock has been altered by carbonization and silicification, he insists that the cinnabar has been exclusively deposited in open spaces, and does not appear as a product of direct replacement of the wall-rock. The quicksilver-deposits are of special interest, because their intimate connection with ascending alkaline waters has been proved. These waters contain but little free carbon dioxide, earthy carbonates and earthy sulphates, but considerable sodic bicarbonate and sodic chloride, and some hydrogen sulphide.

#### 10. *Sericitic Copper-Silver Veins.*

The copper-veins of Butte, Montana, which have been described by Emmons, Weed and Tower,\* form an excellent illustration of this class and, according to Mr. Emmons, are typical replacement-veins. The deposits appear along well-defined fissures in granitic rocks; the principal gangue-mineral is quartz, the primary ores are pyrite, chalcopyrite, zinc-blende and galena. Bornite, chalcocite and covellite are regarded as sulphides formed later under secondary influences. In the vicinity of the veins the country-rock is impregnated with vein-material, generally pyrite and quartz. An impregnation of enargite has also been observed. Sericite and, later, kaolin have also been developed in the rock. The extent of the altered zone is generally proportional to the size of the ore-bodies, and may extend to a distance of 100 feet from the vein. According to the proportion of copper in such an altered mass it may constitute pay-ore or be considered as barren material.

#### 11. *Silicic and Dolomitic Silver-Lead Veins.*

The association of silver-lead deposits with limestone and other calcareous sedimentary rocks is a well-known fact, occurring again and again in all parts of the world. Very many of these deposits are not fissure-veins, or connected with such. But even among those genetically related to fissures, the ores

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\* Folio 38, *U. S. Geol. Surv.*



seldom form well-defined tabular masses, but occur mostly as irregular bodies, while the ducts through which the solutions found access have received but scanty deposits of ore. This is due to the great tendency of galena and zinc-blende, which in these deposits form the principal ore-minerals, to replace the limestone. Beyond doubt such a replacement very often occurs. It was convincingly established by Mr. Emmons in Leadville, Colo., and by Mr. Curtis in Eureka, Nev. In both these cases the demonstration was furnished by the study of structural relations, without the aid of microscopic examination. Indeed, the latter was scarcely possible, since in both these mining districts operations were still in the zone of oxidation, which obscured the relations of primary ore-minerals to the limestone. Since these reports were published, the conditions governing the replacement of the galena have not been greatly elucidated, except in Spurr's study of the Aspen district. The chemical reactions involved were, and are yet, in some doubt; the principal question being whether the galena was reduced from solution of sulphate of lead or deposited from sulphide solution (See p. —). The microscopic study of the attending phenomena must help to settle this point.

The ores are accompanied, either by a gangue of jasperoid, cherty rocks chiefly composed of silica, or by different carbonates, such as calcite, dolomite or siderite. (Those accompanied by a siderite gangue will be treated as a separate class.) Sericitic minerals are absent. The gangue-minerals mentioned have also very largely replaced the limestone.

In the Elkhorn mine, Mont., studied by W. H. Weed,\* bodies of galena appear in a crystalline limestone and are directly connected with a fissure-vein. The beginnings of replacement are shown in specks of intergrown galena and pyrite, scattered through the rock, and always accompanied by small crystals of secondary quartz. The larger grains of galena are surrounded by a narrow rim of pyrite (see page — and Fig. 29).

Mr. Emmons describes the fissure-vein of the Queen of the West mine, Ten Mile district,† Colorado. The principal fissure is partly filled with barren calcite, while galena and blende re-

\* Unpublished notes.

† Folio 48, *U. S. Geol. Surv.*



place the country-rock, consisting of sandstone and intercalated sheets of porphyry. The vein is characterized, besides, by a number of parallel fault-planes, from which replacement has taken place.

*Aspen, Colorado.*—Mr. Spurr, in his description of the Aspen district,\* with its wonderfully complicated system of faults, has given a valuable description of the metasomatic processes there observed. The Aspen deposits are not, strictly speaking, fissure-veins. The ores form irregular bodies of lead- and silver-minerals in limestone; but these irregular bodies are closely connected, genetically, with faults which yielded a pathway for the ascending waters. The processes consist in dolomitization, ferration, silicification, and lastly, the introduction of metallic sulphides. The ores occur in part as filling of pre-existing cavities, but more generally replace the limestone adjoining the fissures. The dolomitization which proceeds irregularly from the fissures is well shown under the microscope, the coarse calcite being broken up into smaller rhombohedral crystals of the yellowish tinge characteristic of dolomite. Silicification usually accompanies dolomitization. In the limestones the process goes on in the following manner. Many tiny quartz-grains first appear scattered through the rock, chiefly along areas of slight shearing or fracture (Fig. 3). Here and there appear long slender quartz crystals, entirely surrounded by fresh limestone. As silicification proceeds, the slender crystals multiply, forming a characteristic network, sometimes enclosing small areas of calcite which are sprinkled with small, irregular quartz-grains, down to the most minute dimensions. The final result is a rock made up of crystalline quartz-grains of varying size, in which the retiform structure is still apparent (Fig. 4), and which rock resembles a chert or a fine-grained and altered quartzite, and is generally somewhat porous, drusy, and also often colored red or yellow. In structure, appearance and origin, this cherty rock is identical with the jaspers of Lake Superior. Mr. Spurr proposes "jasperoid" as a term for this rock, consisting essentially of cryptocrystalline, chalcedonic orphanero-crystalline silica formed by the replacement of other rocks, chiefly limestone. At Aspen this jasperoid forms big reefs along fault-lines.

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\* J. E. Spurr, Monograph XXXI., U. S. G. S.



Dolomitization and silicification are always accompanied by a certain amount of ferration. Usually the iron appears in the partly silicified rocks as small rhombohedrons of siderite; but pyrite is also present, and in many cases the two minerals have been deposited simultaneously.

In the final process of mineralization, the altered limestone is always traversed by reticulated fractures. In every case the ores are first introduced along these crevices; and often this is the only method of mineralization. With greater alteration, metallic minerals penetrated from the fractures into the rock on both sides. The solutions traveled between adjacent crystals of calcite or dolomite, and also along the cleavage-planes of these minerals. In this manner a still finer network was formed, which, by spreading and consolidation, resulted in a continuous mass of sulphides. There is no doubt, Mr. Spurr says, that this is an actual process of replacement; the calcite or dolomite being taken up, molecule by molecule, and replaced by metallic minerals. The sulphides are often accompanied by granular quartz and dolomite, the relations of which show that they have been simultaneously deposited.

#### 12. *Sideritic Silver-Lead Veins.*

In this class, which, like the preceding, ordinarily occurs in sedimentary rocks, not much secondary silica is formed. The principal gangue-mineral is siderite, often accompanied by other carbonates, and nearly always also with some pyrite; in fact the co-existence of pyrite (often also marcasite) and siderite is a notable feature. The other principal ores are galena and zinc-blende. The Eureka, Nev., deposits probably belong to this type.

*Wood River, Idaho.*—Prominent representatives of this class are the Wood River silver-lead veins, near Hailey, Idaho,\* which occur chiefly in calcareous carboniferous shale, and are of pre-Miocene age. In the structure of the vein and arrangement of the ore-bodies replacement is clearly indicated; and galena often occurs as scattered grains throughout the shale. But some filling of pre-existing cavities has also taken place.

The rocks clearly contain much organic material; and the theory of deposition by the reduction of lead sulphate is pos-

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\* W. Lindgren, 20th Ann. Rept. U. S. Geol. Surv., part iii., pp. 189 to 223.



sibly applicable. But this argument is greatly weakened by the occurrence of veins of the same composition in a neighboring body of granite.

*Cœur d'Alene Mountains, Idaho.*—There exist, perhaps, no better instances of metasomatic fissure-veins than the celebrated silver-lead deposits of the Cœur d'Alene mountains, in Northern Idaho. They are clearly defined fissure-veins cutting fine-grained greenish quartzites and quartzitic slates of doubtful (though probably Algonkian) age. The principal ores are galena and zinc-blende, but there is also much finely distributed pyrite. Chalcopyrite is ordinarily absent. These are practically the only metallic minerals, and recur in all the deposits. The principal gangue-mineral is siderite, accompanied by minor quantities of quartz and barite. Fluorite is absent. The fissures along which the ore-bodies appear are well defined, and sometimes continuous for one or more miles. The ore-bodies do not show much clearly defined crustification or other evidence of having been deposited in open space. The siderite appears always as an undoubted product of replacement, while many veinlets of quartz have in part resulted from the filling of open small fissures. Evidences of gradual transitions from ore to country-rock are abundant, and are especially prominent in the mines carrying low-grade ore, as, for instance, in the Helena and Frisco. In the exposures underground, as well as in the specimens and thin sections, the evidence of replacement is complete and positive.

The greenish-grey fine-grained quartzite, which constitutes the prevailing country-rock, contains no sulphides when fresh. It is composed of small, rounded, or subangular quartz grains, closely packed—often, indeed, jointing closely, as in a normal quartzite. Usually, however, a little sericite, in bunches of small fibers, is present as cementing material between the grains. This sericite is apparently an autogenetic mineral, formed during the metamorphism of the sandstone to a quartzite. Occasionally small foils of it project into the quartz, showing a slight incipient sericitization of the latter mineral. There are few other minerals, except a little feldspar in elastic grains, small prisms of tourmaline, and some grains of calcite. Near the veins minute specks of siderite, zinc-blende, pyrite and galena appear in this quartzite; and these scattered grains



gradually merge into bodies containing 3 per cent. and more of galena, thus forming a merchantable ore. The thin sections show how the rock near the veins is filled with small grains of branching and irregular form, which consist of siderite, developed by attack first upon the ground-mass and then upon the grains of clastic quartz. This process is well shown in Fig. 16, which is reproduced from a thin section of Helena and Frisco country-rock. Accompanying the siderite are small grains of zinc-blende, cubes of pyrite and irregular wiry masses of galena. All these sulphides appear not only in or near the siderite, but also in the cementing sericite, and in the apparently perfectly fresh quartz grains.

At a more advanced stage (Fig. 17) these areas of siderite extend until they join, and thus completely replace the rock. In the specimen from which Fig. 17 was taken, masses of siderite are seen to be merging gradually into the fresh quartzite. In the resulting ore lie scattered many small quartz grains, representing remnants of the clastic constituents of the quartzite. Occasionally larger masses of zinc-blende appear to form directly in the quartzite by metasomatic replacement of the quartz. The sericite in the quartz then disappears, though once in a while small foils of it may be detected. During the transition stage, seams and narrow veinlets in the altering rock are filled with sericite, apparently segregated there, when driven out from the main mass. In other specimens from the Helena and Frisco mine, the replacing siderite has a strong tendency to idiomorphic development. Imperfect rhombohedral forms are often seen, sometimes cutting straight across the clastic grains (Fig. 18). Certain specimens from the Bunker Hill and Sullivan mine show quartzose greyish masses of irregular outline, and apparently merging gradually into the normal greenish quartzite. These quartzose masses consist of very irregular interlocking grains of quartz, not in the least similar to the quartz usually deposited by processes of filling, but having every appearance of resulting from the silicification of the quartzite. This silicified portion contains irregular grains of pyrite, galena and brown zinc-blende, with a very little siderite.

The process, as outlined, is remarkable, as involving a metasomatic replacement of quartz by siderite, pyrite, galena and zinc-blende, and is the only clearly defined occurrence of this kind of which I am aware.



This description would not be complete without mention of certain interesting veinlets produced by replacement in the Bunker Hill and Sullivan quartzite. Certain specimens from this mine show a dark greyish-green, very fine-grained quartzite, traversed by minute veinlets, carrying quartz and surrounded by a greenish material. Under the microscope the rock is seen to be a typical fine-grained quartzite or quartzitic sandstone. The grains are separated, not only by fibers of muscovite, but also by a green mica, probably related to biotite. The veinlets are clearly formed by replacement along narrow cracks, and contain a mass of green mica in fine distribution, diminishing away from the seam, together with quartz, garnet, brown zinc-blende, and small prisms of tourmaline, and a small quantity of galena. I have mentioned these peculiar products of replacement because they differ so completely from the deposits as described above. Their formation must be sought in some local cause, involving a change in the mineral-bearing solutions; or in the conditions of the deposition. The presence of garnet in these veinlets is especially remarkable, as this mineral rarely occurs in fissure-veins.

### 13. *Sericitic Lead-Silver Veins.*

*The Clausthal Veins.*—The alterations produced in the clay slates adjoining the vein-system of Clausthal have been described by Groddeck.\* The fissure-veins at Clausthal, which principally carry galena, pyrite and zinc-blende in quartzose gangue, are enclosed in black clay slate belonging to the Culm formation; and to the eye these slates, when enclosed in the vein or lying close to it, ordinarily present no alteration, except such as may result from mechanical deformation or crushing. By a series of analyses, Groddeck has shown that, as a matter of fact, these wall-rocks have suffered alteration considerable in degree, although not apparent to the eye. Some average analyses are given in Table VI.

Comparing the first two analyses, it is apparent that a large part of the protoxide of iron has been carried away, and that at the same time the magnesia has been considerably reduced. These subtractions result in an apparent increase of the other

\* "Studien, Über Thonschiefer, Gangthonschiefer und Sericitschiefer." *Jarbuch der königl. preuss. geol. Landesanstalt*, 1885, pp. 1 to 53.



TABLE VI.—*Analyses of Clausthal Rocks.*

	I.	II.	III.
	Per cent.	Per cent.	Per cent.
SiO <sub>2</sub> .....	56.59	59.31	79.12
Al <sub>2</sub> O <sub>3</sub> .....	23.14	23.72	13.93
Fe <sub>2</sub> O <sub>3</sub> .....	.61	1.13	.44
FeO.....	4.87	1.06	.....
MnO.....	.....	.....	.....
MgO.....	1.80	1.11	.....
CaO.....	.35	.36	.....
K <sub>2</sub> O.....	3.05	3.91	3.18
Na <sub>2</sub> O.....	.75	.80	.64
H <sub>2</sub> O.....	4.01	4.60	1.56
Rutile.....	.38	.23	not dt.
Carbon.....	.64	.95	not dt.
Pyrite.....	.67	.85	not dt.
Apatite.....	.14	.....	not dt.
Carbonates.....	2.56	2.02	1.60

I. Black normal clay slate of the Culm formation. Average of three analyses.—II. Black clay slate adjoining the vein or enclosed in it. Average of seven analyses. These black altered clay slates are always present in or along the veins.—III. Variegated clay slate adjoining the vein. Average of four analyses. These variegated slates are apparently extreme forms of alteration, and are conspicuous by means of their red or yellow color. It is remarked, however, that this form of alteration is an unusual one, only appearing locally in a few mines. The processes to which these altered rocks have been subjected are considered to have been different in kind from those producing the ordinary black altered slates.

constituents. Very notable is the fact that the alkalis remain nearly constant, and that no soda has been subtracted—a most unusual case. The lime, rutile, carbon, pyrite and carbonate have suffered but little change. The amount of alumina is almost identical in the two analyses; and on the assumption that this constituent has remained constant, the two analyses can be directly compared.

Comparing the first with the third, a very strong increase in silica and decrease in alumina is noted, accompanied by an almost complete disappearance of the protoxide of iron, magnesia and lime, the alkali apparently remaining practically constant. It is clear that the alumina has been carried away to a considerable extent, and the process is, on the whole, similar to the alteration which results from the action of the solutions containing free sulphuric acid on aluminous rocks. Sericite and chlorite form part of the fresh rock, and the former is a prominent constituent of the altered rocks. Basing the calculations on the following formulæ:



Sericite,  $2\text{H}_2\text{O} + (\text{K}_2 \text{Na}_2 \text{Ca}) \text{O} + 3 (\text{Fe Al})_2 \text{O}_3 + 6\text{SiO}_2$ ,  
and

Chlorite,  $4\text{H}_2\text{O} + 5 (\text{Mg Fe}) \text{O} + \text{Al}_2 \text{O}_3 + 3\text{SiO}_2$ ,

and disregarding the small amounts of carbonate, pyrite, etc., the following results are obtained:

	Fresh clay slate.	Vein clay slate.	Variegated clay slate.
	Per cent.	Per cent.	Per cent.
Sericite, . . . .	39.24	47.45	34.89
Chlorite, . . . .	16.54	4.37	.....
Quartz, . . . .	35.30	34.40	63.24

These are the averages of the calculations of all the analyses. The character of the alteration is thus clearly seen to consist in a chemical change of the chlorite into sericite, with simultaneous subtraction of FeO and MgO. The quartz is practically constant.

In the case of the variegated clay slates, the change appears to be of a different kind. A comparison of the third column with the first shows that the following reactions have taken place: 1. The chlorite has been completely destroyed; its bases have been carried away, and its silica has probably been added to the free quartz. 2. The percentage of sericite has been diminished (more, in fact, than the 4 per cent. shown by the comparison of the calculations, since we must consider the amount of the bases carried away). 3. The percentage of quartz has been increased by the introduction of free silica besides that obtained from the alteration of the sericite and the chlorite. It must again be emphasized that this process points to the action of a solvent, probably sulphuric acid, capable of carrying away considerable amounts of alumina.

*The Democrat Vein, Hailey, Idaho.*—The Carboniferous strata near Wood river, Idaho, contain masses of intrusive granite, or, as more specifically determined, quartz-monzonite.\* This rock is cut by fissure-veins containing galena, sphalerite and tetrahedrite, with siderite and calcite gangue; the ore being due, partly, to filling of open fissures, partly to replacement. For a few feet on each side of the vein, the granite is altered and contains some pyrite, galena and zinc-blende. The altered rock is of greyish-green color and its texture unmistakably indicates its derivation. The biotite of the granite is converted

\* W. Lindgren, 20th Ann. Rept. U. S. Geol. Surv., part iii., pp. 205 and 211.



to large foils of muscovite; the feldspars are also completely changed to radial tufts and scaly aggregates of sericite, mixed with calcite grains. The quartz grains are in places vigorously attacked by sericitization and carbonatization, in the manner illustrated in Fig. 13. The apatite is completely unaltered, and the titanite is converted to bunches of rutile needles. A little chlorite remains. For complete analyses and calculations, the reader is referred to the report cited. The altered rock consists of: Quartz, 55.07; sericite, 31.78; chlorite, 7.21; calcite, 4.39; siderite, 0.05; rutile, 0.40; apatite, 0.23; pyrite, 0.19; pyrrhotite, 0.07; zinc-blende, 0.14; water (hygroscopic), 0.37; total, 99.90 per cent.

From the determination of specific gravity it is concluded that no change of volume has taken place, but the granite has altered to an aggregate of denser minerals; the result being a rock of considerable porosity. On this basis, namely, the comparison of equal volumes, the following changes, expressed in kilograms per cubic meter, have taken place:

TABLE VII.—*Gains and Losses of Country-Rock of the Democrat Vein, Idaho, During Alteration.*

	GAIN.		LOSS.	
	Per Cubic Meter of Original Rock.	Percentage of, for Each Constituent.	Per Cubic Meter of Original Rock.	Percentage of, for Each Constituent.
	Kilos.	Per cent.	Kilos.	Per cent.
SiO <sub>2</sub> .....	.....	.....	49	2.7
TiO <sub>2</sub> .....	.....	.....	3	2.3
Al <sub>2</sub> O <sub>3</sub> .....	.....	.....	99	24.7
Fe <sub>2</sub> O <sub>3</sub> .....	.....	.....	10	61.6
FeO.....	22	42.3	.....	.....
MnO.....	3	150.0	.....	.....
CaO.....	.....	.....	6	8.5
SrO.....	.....	.....	1	100.0
BaO.....	.....	.....	3	100.0
MgO.....	.....	.....	18	56.2
K <sub>2</sub> O.....	.....	.....	33	29.0
Na <sub>2</sub> O.....	.....	.....	80	93.0
H <sub>2</sub> O below 105° C.....	.....	.....	5	35.8
H <sub>2</sub> O above 105° C.....	31	155.0	.....	.....
P <sub>2</sub> O <sub>5</sub> .....	.....	.....	1	25.0
CO <sub>2</sub> .....	43	nearly all.	.....	.....
S.....	4	nearly all.	.....	.....
Fe.....	3	all.	.....	.....
Co, Ni.....	.....	.....	.....	.....
Zn.....	2	all.	.....	.....
	108		308	



The result shows a total loss of substance of 200 kilograms per cubic meter. The losses extend over all the bases and the silica; baryta and strontia being completely removed without the appearance of barite in the vein. The gains chiefly consist in water, carbon dioxide, ferrous oxide, sulphur and zinc. Both potash and soda are removed; the former only partially, the latter almost completely. Calculated without regard to porosity, by comparing equal weights, the result is reached that the rock has received an addition of substance; but the manner here indicated is doubtless the correct way of regarding the process.

#### 14. *Zeolitic Copper-Veins.*

The copper-deposits of Michigan are in part fissure-veins cutting across the beds of melaphyre and other basic igneous rocks so common in that district. It is true, however, that the ore-bodies of the large mines are not to be considered as fissure-veins, but rather as beds or strata along which copper has been deposited by a process of replacement. R. Pumpelly\* investigated the copper-deposits of Michigan and published part of his results in 1873. Further contributions to the same subject are found in his celebrated paper on "The Metasomatic Development of the Copper-Bearing Rocks of Lake Superior."† In these investigations the theory of metasomatic replacement was applied to American ore-deposits, and in this field Prof. Pumpelly is clearly the pioneer in this country. The copper-bearing veins contain a number of minerals not ordinarily present in fissure-veins, and are, therefore, of special interest. Among these minerals are the zeolites: laumontite, apophyllite and analcite. There are also present as gangue minerals, prehnite, datolite, chlorite, delessite, calcite, orthoclase and quartz. The principal ore-mineral is, of course, the native copper. Of sulphides, chalcocite and bornite are sometimes, but very rarely, encountered.

According to Pumpelly's description, the veins must be due in part to filling; but very largely, perhaps predominantly, the ore results from metasomatic replacement. The stages of this alteration Prof. Pumpelly considers to have been: 1. A forma-

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\* *Geol. Surv. of Mich.*, vol. i., part ii.

† *Proc. Am. Acad. of Arts and Sciences*, vol xiii., 1877-78, p. 253.



tion of chlorite in the amygdaloid rock; 2. Individualization of non-alkaline silicates, such as laumontite, prehnite, and epidote; 3. Deposition of quartz; 4. Introduction of native copper, accompanying which there was a replacement of prehnite by a green earth or delessite, often intimately connected with the copper; 5. Appearance of the alkaline silicates, such as apophyllite, orthoclase and analcite.

This occurrence of secondary orthoclase or adularia is of special interest in view of the fact that the same mineral has lately been found to form an important gangue-constituent in certain Tertiary fissure-veins in volcanic rocks of the West. It is considered that the alkaline silicates represent the final stage, namely, the decomposition of the labradorite of the original rock, while the chloritization represented the first stage of alteration, namely, that of ferro-magnesian silicates to chlorite. Prof. Pumpelly thinks that copper was originally present as sulphides in the rocks, and that the changes, consisting in leaching and re-disposition in veins, have been effected by surface-waters carrying carbonic acid and some atmospheric oxygen. The copper was deposited after the destruction of the ferro-magnesian minerals, and before the deposition of the products from the decomposition of the feldspars. From the state of sulphide, copper was converted to silicate, carbonate and sulphate. These salts were then reduced to a metallic state. He thinks also that there is a close genetic relation between this metallic copper and the ferric condition of the iron oxide in the associated silicates. The oxidation of the iron was caused by the reduction of the oxide of copper at the expense of the oxygen of the latter.

Prof. R. D. Irving, in his report on "The Copper-Bearing Rocks of Lake Superior,"\* confirms in general the conclusions of Prof. Pumpelly. He considers the veins as very largely replacement-veins not sharply defined from the surrounding rocks, but simply the result of a rock-alteration entirely analogous to that which has brought about the deposition of copper and its associated vein-stone minerals within the cupriferous amygdaloids. They are alteration-zones, which traverse instead of follow the bedding. The replacement of wall-rock by cop-

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\* Monograph V., *U. S. Geol. Surv.*, 1883.



per masses is a common occurrence; and the paragenesis of the vein-minerals is identical with that of the copper-bearing amygdaloid rocks.

Especially remarkable is the series of replacements which, as shown by Pumpelly, has taken place in these veins. Prehnite is pseudomorphic after plagioclase; and many amygdaloids are largely prehnitized. This prehnite is again replaced by orthoclase; and finally, the latter may change into epidote and quartz. Sericite is absent.

These copper-bearing veins are clearly very different from the majority of fissure-veins, and have been formed under very different conditions—in fact, probably not by thermal waters. Of other classes, the orthoclase-albite-zeolite veins of the Alps are most closely related; while a certain slight resemblance also exists to the propylitic veins, emphasized by the chloritic alteration and the presence of orthoclase.

The veins of Kongsberg, Norway, and Andreasberg in the Hartz mountains, both of which also carry zeolites, are not sufficiently known in their metasomatic aspects to be discussed here.

*Observed Alteration by Ascending Waters.*

Extremely little exact work has been done in this most important line of investigation, namely, to ascertain actual alterations by waters of known composition. In veins we usually have only the altered rock as a known quantity, and must endeavor to draw conclusions from this as to the character of the waters.

Most interesting and well known is Prof. Daubrée's discovery of the alteration which the old Roman bricks and mortars have suffered at the place where the mineral springs of Plombières break through the granite, ascending on fissures carrying fluorite and quartz. The waters are thermal, having a temperature of 70° C., and may be characterized as weak mineral waters, containing sulphates and chlorides, with a little hydrogen sulphide; silicates of potash and soda are also present in them. In the bricks employed by the Romans as curbing for the spring, a number of minerals have been deposited. Chief among them are the zeolites. Chabazite, mesotype, and apophyllite are the principal minerals formed in the pores and spaces of dissolution in the old bricks. Besides



these, opal and chalcedony have been deposited; and, on one piece of mortar, fluorite, scalenohedrons of calcite, and prisms of aragonite were also found. This is extremely interesting, as the fissures on which the spring rises contain much fluorite. The apophyllite also was found to contain a notable percentage of fluorine. An analysis of this altered brick gave the following result:  $\text{SiO}_2$ , 19.39;  $\text{Al}_2\text{O}_3$ , 17.33;  $\text{Fe}_2\text{O}_3$ , 5.37;  $\text{CaO}$ , 51.40;  $\text{MgO}$ , 0.75;  $\text{K}_2\text{O}$ , 5.94;  $\text{Na}_2\text{O}$ , 0.33; total, 100.51 per cent.

In this analysis the most remarkable fact is the strong prevalence of potash and the small quantity of soda present. It is scarcely to be assumed that the ordinary bricks of that locality contained the alkalis in this proportion. The porous bricks were evidently specially adapted for the formation of new minerals, and the large percentage of lime in the mortar also facilitated the process. Daubrée mentions that pieces of granite enclosed in the same mass show no zeolitization, and refers at the same time to the fact that pyroxene and feldspar show no alteration in the same superheated glass tubes in which glass is completely transformed into zeolites and into silica. This shows in a striking manner the dependence of the alteration of the country-rock upon its structure and composition.

Mr. W. H. Weed has recently\* found a mineral vein in process of formation by a weak thermal water at Boulder, Montana. The vein-filling consists of quartz, calcite and some stilbite, while the adjoining granite is partly altered to sericite and kaolinite; these two minerals attacking all of the primary constituents (Fig. 19). A little free silica is also mixed with the kaolinite. In some specimens the kaolinite and sericite are subordinate and the feldspar appears partly silicified.

#### CONCLUSIONS.

Some of the following conclusions, drawn from the data presented in this paper, may seem trite repetitions of already known facts; but it is perhaps well to remember that our knowledge of the genesis of mineral deposits is not built on such firm foundations that it does not need fortification of its position by conclusions from all possible view-points.

1. Almost all fissure-veins are bordered by altered zones of

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\* *Trans.*, Washington Meeting, Feb., 1900.



varying extent and intensity of alteration. In the so-called "replacement-veins" this altered and replaced rock contains the valuable ore.

2. The metasomatic processes in different classes of veins show an almost kaleidoscopic variety. In one class of veins, quartz may be converted into calcite, while in a different class calcite may be converted into quartz. The action is usually intense, involving a great change in the chemical composition.

3. The hydration connected with the alteration is only very moderate.

4. The most prominent mineral formed by the metasomatic processes is a potassium mica (muscovite, sericite, zinnwaldite and many other related species). The most prominent process is the progressive elimination of soda and concentration of potash, closely connected with the formation of potassium mica.

5. The metasomatic processes in fissure-veins differ distinctly in most cases from those involved in ordinary static, dynamic and contact metamorphism, and the two classes of change have not generally taken place under the influence of the same conditions and agencies. Greisen is only found near cassiterite-veins. Granite, thoroughly changed to sericite, calcite and pyrite, is never found as a result of any other metamorphism than in fissure-veins, nor are fluoritized or sideritized rocks so found. The propylitic and biotitic alteration; the chloritic and zeolitic alteration of Lake Superior copper-veins; and the silicification in limestone and other rocks form exceptions, being similar to certain developments of dynamic, static and hydrochemic metamorphism.

6. Ordinarily, the alteration consists in the total or partial loss of certain constituents; the gain of others; and the introduction of new compounds and elements, usually carbon dioxide and sulphur. The net total of the change per unit of weight or volume may be a gain or a loss, perhaps more often the former. If sulphides are abundantly introduced, the result will usually show a strong gain in mass.

7. The processes observed are such as can only be explained by aqueous agencies. Possible exceptions are the forms of alteration connected with cassiterite, apatite and tourmaline-veins, in which pneumatolytic conditions may have partly obtained.



8. The intensity of the processes observed indicates that the aqueous solutions acted under moderately high temperature pressure and concentration. No cold, pure surface-water could produce such results as are ordinarily found.

9. From the fact that the substances introduced, such as sulphur, carbon-dioxide, fluorine, boron and heavy metals, are only known to be contained in noteworthy quantities in thermal waters ascending on fissures, it is concluded that these waters were the agencies usually active in the process of alteration.

10. Many of the substances found in the filling of the open spaces along the fissure may be lacking in the altered rock, showing that the latter forms a septum not penetrated with equal ease by all constituents of the solution.

11. The ascending waters are chiefly surface-waters, which, after a circuitous underground route, have found in a fissure an easy path on which to return. During their long downward passage they doubtless dissolve much material from the rocks which they penetrate; and this solution was facilitated by the gradually increasing heat and pressure with increasing depth. During the ascending period, much of this material is deposited. The metasomatic action on the wall-rock results in further exchanges of constituents, some being dissolved and others deposited.

For many veins, this genetic theory may be fully sufficient. But for many others, perhaps for the majority of fissure-veins, something seems to be lacking in this explanation. The difference in the metasomatic processes in veins and in other forms of metamorphism must be taken into consideration, as well as the abundance of certain constituents, such as carbon dioxide and hydrogen sulphide, in mineral waters. The presence of these constituents has not been satisfactorily explained, and cannot be, except in certain cases, on the theory of solutions derived from the solid country-rock.

I believe that the majority of fissure-veins are genetically connected with bodies of intrusive rocks, even when the actual deposits are contained in the overlying surface lavas. It is well known that the intrusive rocks, such as granite, diorite and gabbro, may contain at the time of their intrusion water, carbon dioxide, fluorine, boron and sulphur. Under decreas-



ing pressure, these substances have a tendency to leave the cooling magma; and as many of them form, with the heavy metals also contained in the magma, volatile compounds with a low critical temperature, these heavy metals may be carried away from the magma along with the "mineralizing agents" mentioned above. This is the well-known theory which was originated by Elie de Beaumont and Daubrée, and developed by other French investigators; but until recently it has hardly received the attention which it deserves. The results of these emanations is shown in the contact metamorphism and in the mineral deposits often appearing near the boundaries of intrusive bodies. Where fissures traverse the cooling magmas, and the rocks surrounding them, it is natural that these mineralizing agents carrying their load of heavy metals should ascend, at first under pneumatolytic conditions, above the critical temperature. Reaching the zone of circulating atmospheric waters, it is natural that they should mix with these, which probably greatly predominated in quantity. To this combination of agencies, found in the ascending waters of such regions of igneous intrusion, the formation of most metalliferous veins is probably due. This dependence of veins on intrusive bodies is most clearly perceived in certain cassiterite-, apatite- and tourmaline-veins; but from these all sorts of transitions may be found, to veins of more ordinary character.

I am by no means prepared to deny that some classes of veins may be due to circulating surface-waters alone; but I do not believe that the dissolving power of the latter is sufficient to account for all classes, or even for the majority, of fissure-veins.



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## Metasomatic Changes in Veins.

Discussion of the Paper of W. Lindgren, read at the Washington Meeting,  
February, 1900.

BY PROF. FRANK D. ADAMS, MCGILL UNIVERSITY, MONTREAL, CANADA.

MR. LINDGREN'S paper is a valuable contribution to the literature of ore-deposits, bringing together as it does a great number of facts concerning the metasomatic changes developed by vein-forming solutions in the rocks which they traverse. It is also of much interest as an attempt to classify mineral veins according to the character of the metasomatic changes which accompanied their development, and especially according to some *predominant* metasomatic mineral, which they contain. This principle, however, as Mr. Lindgren remarks, seems to have serious limitations when adopted for purposes of classification—one of these being the fact that the same waters may give rise to different metasomatic minerals in the case of different rocks.

Furthermore, just as the various magmas with which Mr. Lindgren considers the various kinds of vein-making solutions to be severally connected pass into one another by imperceptible gradations, so do these solutions also; and thus, instead of a series of well-defined classes of mineral veins, an almost continuous series will be met with in nature. This difficulty, however, is shared by all systems of petrographical classification, and by most of the other systems proposed for the classification of mineral veins.

In the case of the cassiterite-veins (Mr. Lindgren's Class I.), for instance, the *predominant* metasomatic mineral is said to be topaz; but in the most extensive deposits of this class which are known—those of Cornwall—the predominant metasomatic mineral would appear rather to be tourmaline.

In the apatite-veins (Class II.), scapolite is taken as the predominant metasomatic mineral. This is true of the Norwegian deposits; but in the Canadian deposits, which are even more



extensive, while this mineral is very common, it cannot be considered as *predominant*. These Canadian deposits, while in many cases at least occurring in association with basic igneous rocks, as in Norway, are usually found, not in contraction-joints of the intrusive itself, but as veins cutting the limestones and associated rocks of the Laurentian, which are penetrated by these intrusives. The apatite, unlike that of Norway, is a fluor-apatite, not a chlor-apatite; and the predominant metasomatic mineral is malacolite. So notably is this the case that the prospectors in the apatite-districts always look for "pyroxene," and regard it as an almost certain indication of phosphate in the vicinity. Next in abundance to the malacolite is, perhaps, mica (phlogopite and biotite), which in some cases is present in such large amount that apatite-mines which were abandoned on account of the fall in price of that mineral in the years 1893-94 have been, by reason of the more recent demand for phlogopite, opened up and worked anew for this latter mineral. While, therefore, the Norwegian and the Canadian apatite-occurrences undoubtedly belong to the same class of deposits, the former is characterized by the presence of chlorine minerals, while in the latter this element is largely replaced by fluorine, which is also so commonly found in association with cassiterite-veins. The chlorine-bearing scapolite thus cannot be considered in all cases as the *predominant* metasomatic mineral required by the definition of Class II.

Mr. Lindgren's views concerning the close genetic association of most mineral veins with igneous masses seem to be abundantly supported by the facts, as also his conclusions with regard to the preponderating influence of pneumatolitic action in the case of the cassiterite- and apatite-veins, as shown by the constant association of chlorine-, fluorine-, boron-, phosphorous-, titanium-, and lithium-minerals with them.



### Metasomatic Processes in Fissure-Veins.

Discussion of the Paper of Mr. Lindgren, presented at the Washington Meeting,  
February, 1900.

BY CHARLES R. KEYES, DES MOINES, IOWA.

WE are certainly deeply indebted to Mr. Lindgren for so excellent a review of the subject of molecular interchanges associated with the production of ore-bodies occupying fissures. The importance of considering the changes of the wall-rocks of ore-veins has certainly never been adequately recognized. Lying, as it does, in no-man's land, between the territory of the miner and the province of the petrographer, the subject has been sadly neglected by both, instead of being made mutually productive.

While there is, no doubt, great need of an agreed technical terminology to express the multifarious conceptions and the various shades of meaning, I very much question the wisdom of even attempting to adapt, at least in its entirety, the petrographical nomenclature, already well established, to the recognized phases of ore-formation, where processes are not so well understood, and exact terminology must necessarily remain for some time yet indefinite.

The meaning commonly ascribed to metasomatism, when applied to ore-deposits, seems somewhat unhappily chosen. We sometimes get a clearer insight into things by referring to them under older and entirely different names. The title metasomatism as used by Mr. Lindgren is, I take it, almost, if not exactly, co-extensive with the somewhat older term of mineralogical metamorphism. The latter term has been widely used by petrographers generally, and has come to have a special significance in connection with the microscopic study of rock-masses.

So far as ore-deposits are concerned, these two terms may be, without serious impropriety, regarded as identical and interchangeable. But the fact should not be lost sight of, that



besides strictly metasomatic change, there are other grand groups of molecular changes among which may be mentioned, in particular, paramorphic change. The latter, while it may have no immediate connection with ore-deposits, has an extremely interesting mineralogical rôle, which cannot well be overlooked, and which greatly elucidates some of the broader phases of rock-metamorphism.

As generally used by writers on ore-deposits, the term metasomatism does not signify a simple or definite process, or an assemblage of distinct processes. It is merely a vague title given to an indeterminate group of ordinary chemical activities, in which the only essential feature which the idea carries is that each chemical change is definitely located in space. Among ores it has special emphasis, for the reason that chemical substitution takes place with the desired stationary residuum. Emmons succinctly states the vagueness of the problem when he says that interchange of substance is "not necessarily molecule by molecule," but "in such manner as to preserve the original structure, form, or volume of the substance replaced."

To illustrate more clearly for present purposes, we may fancy a point of limestone bathed by a stream of moving, mineral-laden water. If the limestone substance is gradually carried away we have simple solution; if from out the stream mineral matter is left upon the limestone, we may have simple precipitation or incrustation; but if, as the molecules of limestone are dissolved, new molecules immediately take their places, we have substitution or replacement. This last, however, is not necessarily metasomatism, as I understand it.

To the student of the general metamorphism of rock-masses, metasomatism is a sharply defined chemical process by which, in the solid rock, usually, mineralogical transformation goes on. At least four well-marked phases are readily distinguished. A characteristic molecule may break up into two or more, with little or no addition or substitution of extraneous elements. Or, there may be reactions between adjoining crystals or substances. Or, thirdly, some of the elements entering into the composition of the new minerals may be brought in from a distance. A fourth phase may occur when a foreign substance entirely displaces a component, molecule by molecule. There are still other distinctions that may be made reference to which is not necessary at this time.



In all of these cases, the interchanges are assumed to take place in the rock-mass with no aid from circulatory waters other than those which may move through the ordinary micro-capillary pores of the stone.

In the mineralogical metamorphism of a rock-mass in a region undergoing dynamic compression, such as is initiated by mountain-making forces, the so-called circulatory underground waters are only of secondary importance. The fissures through which these waters pass are relatively local in influence; and changes that may take place along their walls may be regarded as affecting only a very small part of the rock-mass itself.

As thus understood, it is doubtful whether ore-deposits of any considerable extent are ever really formed through true metasomatic action. The conditions under which chemical change goes on in and immediately about cavities in rocks are so different from those under which the mineralogical changes in the rock itself take place that it appears inadvisable to attempt to extend the definition of a term already well established in microscopical petrography, and thereby to do away with its usefulness altogether.

Mr. Lindgren himself, I think, recognizes the force of this factor when he specifically calls attention to the wholly distinct character of the alteration taking place in the body of the rock-mass (to certain phases of which I have considered the term metasomatism restricted) from that of the change or replacement occurring in fissures, and says, "the metasomatic processes in wall-rocks of the fissure-veins differ generally from those of regional (static and dynamic) metamorphism."

The restricted petrographical idea of metasomatism is, no doubt, very attractive for application to ore-deposits. But the already widely-used term replacement seems to cover more fully and more appropriately the analogous phases, as exhibited by the ores.

The main usefulness of the idea of metasomatism, as applied to ore-bodies, is to give rise to a great taxonomic group of deposits which are formed often where no previous cavities existed, and hence to set these off, geologically and genetically, from all other classes of ore-formations.

It is important to note, in this connection, that the period of



maximum activity in the mineralogical change of rock-masses does not often coincide with the period of maximum ore-formation. As a rule, the latter is long subsequent to the former, and is the immediate outcome of activities and conditions wholly distinct.

In its more extended signification, the term metasomatism is not very far from meaning practically the same as chemical change, at least so far as ore-deposits are concerned. In the sense intended by Mr. Lindgren, replacement appears to meet most nearly the requirements imposed by the conditions presented by the ore-deposits. The exact group of chemical processes involved, and the definite set of conditions existing in each particular case, are not what are first sought in ore-exploitation. The usefulness of the distinction is really inversely proportional to its success in avoiding expression of exact values.

In metasomatism proper, as a mode of rock-alteration due to static or dynamic metamorphism, there are recognized a number of distinct phases, the results of varying physical conditions and differences in chemical composition and mineralogical constitution. Such are uralization, sericitization, saussuritization, epidotization, etc. The suggestion of analogous alterations due to contact-metamorphism, or in connection with fissure-veins, does not appear to serve a similar useful purpose; and in the special case of ore-replacement in veins the central idea is completely lost. Topazization, tourmalinization, scapolitization, fluoritization, and the like, do not, to my mind, present practical features for the classification of ore-veins, or features which can be made use of in ore-exploitation.